# Validation of speech-language therapists' perceptions of reflexive cough strength against objective measures of peak flow, pressure and acoustics

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## Abbreviations

| | |
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| AUC | area under the curve |
| C2 | two coughs without intervening inspiration, threshold response |
| CI | confidence interval |
| CRT | cough reflex testing |
| CSE | Clinical Swallowing Evaluation |
| CVA | cough volume acceleration |
| DiSP | Dysphagia in Stroke Protocol |
| FEES | Fibreoptic Endoscopic Evaluation of Swallowing |
| LCR | laryngeal cough reflex |
| L/s | litres per second |
| ICC | Intraclass Correlation Coefficient |
| mmHg | millimetre of mercury |
| MWST | modified water swallowing test |
| PCF | peak cough flow |
| PD | Parkinson's Disease |
| PEFR | peak expiratory airflow rate |
| SD | standard deviation |
| TBI | Traumatic Brain Injury |
| TEV | total expiratory volume |
| V | velocity |
| VAS | visual analogue scale |
| VFSS | Videofluoroscopic Swallowing Study |

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## Abstract

**Introduction:** Clinicians routinely use subjective ratings of reflexive coughing strength to make judgements about an individual's ability to protect their airway in the event of aspiration. It is therefore important to understand the accuracy of these judgements. This study investigated the validity of perception of strength of reflexive coughing as compared to objective coughing measures. Secondarily, reliability of speech-language therapist's perceptual ratings of reflexive coughing strength was investigated.

**Methods:** Data from prior research (Mills, Jones, & Huckabee, 2017), in which participants underwent videotaped cough reflexive testing (CRT) with concurrent measurement of peak pressure, flow and acoustics, were used in this web-based study. This study included two online surveys, each comprising 36 videos of individuals undergoing CRT. Participants first viewed 'very weak' and 'very strong' reflexive cough examples to serve as perceptual anchors. Participants then provided ratings of reflexive coughing strength for each of 36 cough epochs using a visual analogue scale (VAS), which were used to evaluate inter-rater reliability. For intra-rater reliability, the same videos were rated in a re-randomised order after a minimum of 3 days. Reliability was calculated using Intraclass Correlation Coefficient (ICC). Correlations between the averaged VAS scores within a cough epoch and each physiological measure are reported.

**Results:** Eighty-two participants completed ratings for the analysis of inter-rater reliability and validity; 36 provided ratings for intra-rater reliability analysis. Moderate inter- and intra-rater agreements of perceptual ratings were calculated. There was no association between VAS score and peak flow and peak acoustic measures. A moderate positive association was present between VAS score and peak pressure ($\tau_b$ = 0.46, p <0.01). Participant experience level with CRT did not influence validity or reliability of reflexive coughing strength ratings.

**Conclusions:** Research findings suggest that clinician's subjective judgments of reflexive coughing strength are not validated by objective measures of peak pressure, flow or acoustics. In addition, findings of only moderate reliability between clinicians' perceptual judgements, supports the use of objective swallowing and reflexive coughing strength assessment to guide clinical dysphagia management and to accurately determine aspiration

risk. Further research is indicated to determine the clinical utility and value of subjective assessment of reflexive coughing strength.

## 1. Introduction

Dysphagia, or swallowing impairment, can occur as a result of a variety of aetiologies including stroke, progressive neurological conditions, aging and dementia. Aspiration is a common consequence of dysphagia and is defined as food, fluid or saliva entering the lungs, which can potentially lead to aspiration pneumonia and other health complications. Coughing is a key defence mechanism against aspiration by ejecting foreign material from the pulmonary system. When material enters the lungs without a spontaneous coughing response or any other significant signs of distress, this is referred to as silent aspiration. Individuals with neuromuscular diseases are susceptible to aspiration-related respiratory complications due to not only impaired swallowing function, but also reduced effectiveness of spontaneous airway clearance mechanisms (Lasserson et al., 2006). Clinicians routinely use subjective ratings of reflexive coughing strength to contribute to judgements about an individual's ability to protect their airway in the event of aspiration. However, the validity of these perceptual judgements is currently not well understood.

This study investigated the relationship between objective coughing measures and clinicians' perceptual ratings of reflexive coughing strength. Furthermore, clinician inter- and intra-rater reliability regarding perception of reflexive coughing strength was also investigated. In the clinical setting clinicians use subjective judgements of reflexive coughing strength to help guide dysphagia management, therefore it is important to understand the accuracy of these judgements.

## 2. Literature Review

### 2.1 Coughing and its role in airway protection

Coughing is an airway defence mechanism that promotes the removal of inhaled particles or mucus from the airways (Haji, Kimura, & Ohi, 2013). Morice and colleagues describe coughing as "a forced expulsive manoeuvre or manoeuvres against a closed glottis that are associated with a characteristic sound or sounds" (Morice et al., 2007, p. 2). It is a motor process characterised by three distinct phases, an inspiratory phase involving a large inhalation, a compressive phase which requires a forced expiratory effort against a closed glottis, and an expulsive phase signalled by the opening of the glottis and a rapid expiratory flow (Korpáš & Tomori, 1979). Impaired coughing is referred to as dystussia (Pitts & Bolser, 2011). Patients with neuromuscular disease often present with dystussia and dysphagia in parallel, due to the shared neural and anatomical substrates of coughing, swallowing and respiration (Watts, Tabor, & Plowman, 2016). Individuals with impaired coughing are at greater risk of developing aspiration pneumonia (Hammond et al., 2009).

The development of aspiration pneumonia is known to be multi-factorial with an overall mortality rate ranging from 20% to 50% (Langmore et al., 1998). Given the important role that coughing plays in clearing aspirated material from the upper airway (Mills et al., 2017), assessment of coughing effectiveness and strength has traditionally been a key component of the clinical swallowing evaluation (CSE) (Hammond et al., 2009).

### 2.2 Clinical Swallowing Examination

Despite routine use of the CSE in clinical practice, it is known to be sub-optimal in identifying silent aspiration (Wakasugi et al., 2008). A number of studies have investigated the sensitivity of the CSE in identifying aspiration in comparison to objective swallowing assessment outcomes. Splaingard and colleagues compared CSE and Videofluoroscopic Swallowing Study (VFSS) findings in the diagnosis of aspiration. The study recruited 107 participants from a broad range of aetiologies, including adults and children (Splaingard, Hutchins, Sulton, & Chaudhuri, 1988). Forty-three (40%) participants were observed to aspirate on at least one consistency during VFSS. Bedside evaluation only identified 18 (42%) of those observed to aspirate on VFSS. Overall, the positive predictive value of the CSE was 0.75 and the negative predictive value was 0.70. Findings of this study suggest that

CSE in isolation underestimates the frequency of aspiration in a patient population (Splaingard et al., 1988). Broad participant selection (adults and children) in this study may have increased the variability in the sample, therefore making results harder to generalise to the clinical setting.

Terre and Mearin's research similarly investigated the correlation between CSE outcomes and VFSS findings for 138 individuals post stroke (Terre & Mearin, 2006). A statistically significant relationship was demonstrated between penetration to the laryngeal vestibule and changes in voice quality. A significant relationship was not present between the appearance of cough when swallowing and evidence of aspiration on VFSS. However, the components of the CSE in this study were by no means robust. Elements of the CSE were restricted to observation of coughing during oral feeding, changes in voice quality after swallowing and assessment of palatal and gag reflexes (Terre & Mearin, 2006). Therefore, results of this study need to be interpreted within the context of the limited CSE.

Daniels and colleagues have completed multiple studies investigating clinical indicators of aspiration (Daniels, Ballo, Mahoney, & Foundas, 2000; Daniels et al., 1998). An initial study compared outcomes of the CSE and occurrence of aspiration on VFSS (Daniels et al., 1998). Six clinical indicators of aspiration including dysphonia, dysarthria, abnormal gag reflex, abnormal volitional cough, cough with swallow and voice changes after swallow were found to be significantly related to aspiration. The combined clinical indicators of abnormal volitional cough and cough with swallow demonstrated greater sensitivity (69.9%) and specificity (84.4%) that any individual clinical indicator. A further study by Daniels and colleagues assessed 56 patients post stroke using their previously validated clinical swallowing screening tool. Participants presenting with 2 or more clinical indicators of aspiration on the screening tool were referred to VFSS (Daniels et al., 2000). Of these participants, 37% presented with normal swallowing or mild dysphagia, and the remaining 63% presented with moderate to severe dysphagia. Findings from the aforementioned studies suggest that clinical indicators of aspiration observed during the CSE, such as change in voice quality, may have a relationship with aspiration (Terre & Mearin, 2006). Furthermore, combined clinical indicators of aspiration may have a predictive role in identification of aspiration and severity of dysphagia in the clinical setting (Daniels et al., 2000).

More recent research by Suiter and colleagues investigated the agreement of aspiration risk between objective swallowing assessment and a validated swallowing screening tool named the Yale Swallow Protocol. This protocol consists of a 3-ounce water challenge, assessment of oral mechanisms and a brief cognitive assessment. An initial study focusing on the 3-ounce water challenge demonstrated sensitivity to predict aspiration during Fibreoptic Endoscopic Evaluation of Swallowing (FEES) as 96.5%, with a specificity of 48.7% (Suiter & Leder, 2008). This study had a large sample size (n = 3000) and demonstrated that approximately half the participants who presented with clinical signs of aspiration on bedside screening, were subsequently observed not to aspirate on objective assessment. The high sensitivity suggests that if the 3-ounce water test is passed, diet can be commenced without further objective testing. However, the high rate of failure of the 3-ounce water test in this study (61.6% failure rate), and low specificity suggests that the sole use of 3-ounce water test to determine need for objective assessment could potentially result in a high rate of dietary restriction and over-referral for objective testing. Authors identified a limitation of this study being the use of a single non-blinded rater to complete FEES assessment and interpretation.

A further study was undertaken using multiple blinded raters to determine reliability of the Yale Swallow Protocol in predicting aspiration compared to VFSS (Suiter, Sloggy, & Leder, 2014). In this sample of 25 males, the Yale Swallow Protocol demonstrated a sensitivity to predict aspiration of 100%, with a specificity of 64%. This study included a relatively small heterogenous sample which limits applicability of results to the wider population. Whilst the Yale Swallow Protocol demonstrates clinical utility in correctly identifying those not at risk of aspiration, it only shows a small increase in specificity when compared to the 2008 study, suggesting that the additional aspects of the Yale Swallow Protocol (assessment of oral mechanisms and cognition) may not provide significant benefit over the 3-ounce water test alone.

Despite outcomes of the aforementioned studies demonstrating the role of the CSE in predicting aspiration risk, a fundamental limitation of the CSE remains that it does not address laryngeal sensitivity, and consequently cannot reliably identify individuals presenting with silent aspiration.

### 2.3 Cough reflex testing

Silent aspiration occurs when material enters the lungs without a spontaneous coughing response or any other significant signs of distress (Lasserson et al., 2006). The risk of developing aspiration pneumonia increases in individuals demonstrating silent aspiration (Pikus et al., 2003), reinforcing the importance of assessing laryngeal sensitivity. Cough Reflex Testing (CRT) is an acknowledged method of assessing the neurological integrity of vagal nerve sensory fibres (Morice et al., 2007). There are a variety of ways in which CRT can be administered. A common method used in the clinical setting involves delivery of an irritant such as citric acid, capsaicin, tartaric acid or a hypertonic solution at different concentrations in the form of a mist via a nebuliser. This mist is inhaled through a facemask or mouthpiece to elicit a coughing response. An individual's response determines their cough threshold which can then be compared to normative values (Watts et al., 2016). CRT may help identify patients with sensory impairment, who are at risk of silent aspiration and consequent respiratory complications such as pneumonia (Addington, Stephens, Widdicombe, & Rekab, 2005).

Multiple studies have looked at the validity of CRT findings in relation to objective swallowing assessment to further determine its clinical utility. Citric acid is the most commonly documented tussive agent used in CRT studies, with use of other agents such as tartaric acid being far less prevalent. Addington and colleagues utilised tartaric acid to assess laryngeal cough reflex in stroke patients and compared outcomes with VFSS findings and also subsequent development of pneumonia (Addington, Stephens, Gilliland, & Rodriguez, 1999). All 5 patients who developed pneumonia in this study had an abnormal response to CRT, with a sensitivity for aspiration of 17% (5/30); no patient with a normal response to CRT developed pneumonia. Conversely, VFSS was only abnormal in 3 of the 5 patients who developed aspiration. This study is unique in the use of aspiration as a clinically significant endpoint, however the small event rate of aspiration (5 in 131 participants) mean these results require validation on a larger cohort. However, results do suggest that a negative CRT has utility in excluding patients at high risk of aspiration. Further strengths of this study include its clinical applicability, using at-risk patients who have had a cerebrovascular accident. This does however also introduce limitations, such as procedural difficulty in obtaining adequate lip seal with a mouthpiece in cases of facial weakness.

Whilst this is not addressed by the authors of this study directly, effective inhalation was a required inclusion criterion of the study, suggesting that some patients with significant dysphagia may have been excluded from the study.

Wakasugi and colleagues aimed to validate the use of CRT and a modified water swallowing test (MWST) against VFSS and FEES in 204 suspected dysphagic patients (Wakasugi et al., 2008). A single dose approach of citric acid (1.0 w/v%) was administered via a mouth mask. Findings demonstrated that sensitivity of CRT for identifying silent aspiration was 0.87 with a specificity of 0.89. In addition, 104 of these participants also underwent MWST. When CRT was combined with the MWST, 89.1% of these participants were deemed 'normal' on both the combined screening measures and instrumental swallowing assessment. Approximately three quarters of participants (73.7%) diagnosed with 'aspiration with cough' using the combined screening tool also demonstrated aspiration with cough on instrumental assessment. Of the cohort diagnosed with silent aspiration on combined MWST and CRT screening, 88.2% demonstrated silent aspiration on instrumental assessment. These outcomes support the clinical utility of CRT; however limitations are evident in the methodology of this study. Aspiration risk was objectively assessed with either VFSS or FEES. Authors did not detail how many patients were allocated to each assessment, and subsequent calculations of sensitivity and specificity used combined VFSS and FEES outcomes. Inherent differences between VFSS and FEES could potentially introduce bias and reduce accuracy when interpreting the results of this study.

A more recent study by Guillén-Solà and colleagues similarly investigated reliability of CRT in comparison to VFSS outcomes with a subacute stroke population. This prospective study recruited 134 stroke patients and also implemented a healthy control group (n = 21) (Guillén-Solà et al., 2015). Sensitivity and specificity were 19% and 71% respectively, with authors concluding that CRT in isolation was not a useful screening tool for risk of silent aspiration in a subacute stroke population. Similar to the methodology used by Wakasugi and colleagues (2008), a single dose (1.0 w/v%) of citric acid was trialled rather than implementing a dose-response approach. However, Guillén-Solà and colleagues (2015) demonstrated significantly lower sensitivity and specificity levels. Guillén-Solà and colleagues (2015) used VFSS to determine reliability of CRT, whereas research led by

Wakasugi used combined VFSS and FEES ratings (Wakasugi et al., 2008), which was a key methodological difference between the two studies. Furthermore, research led by Guillén- did not report the method of administration of citric acid (Guillén-Solà et al., 2015) which may be a potential factor contributing to differing outcomes and further highlights the need for consistency in CRT methods.

In contrast, Miles and colleagues found that results from CRT were significantly associated with aspiration on both VFSS and FEES with a cohort of 181 patients (Anna Miles et al., 2013). Citric acid was administered in incremental doses to determine optimal concentration to maximise sensitivity and specificity for CRT. Eighty patients underwent VFSS and 101 underwent FEES. Results from both FEES and VFSS assessments were compared separately to CRT outcomes. Optimal doses were 0.6mol/L to correlate with VFSS results, and 0.4 mol/L to correlate with FEES outcomes. Optimal sensitivity and specificity was identified at 71% and 60% respectively for VFSS, and 69% and 71% respectively for FEES. The finding that optimal sensitivity and specificity of CRT was achieved with different doses of citric acid for VFSS and FEES is meaningful. This further highlights limitations of the Wakasugi led research which used a single dose of citric acid and then analysed grouped VFSS and FEES outcomes (Wakasugi et al., 2008). These key methodological differences could have contributed to differing results between the two studies. The results of the research Miles and colleagues (2013) can be interpreted with more certainty due to a more rigorous description of methods and rationale for procedures.

Different levels of sensitivity and specificity are apparent in the aforementioned studies. This is not unexpected given variability in method of administration and dosage of citric acid, as well as variability in selection of the comparative objective swallowing assessments. Miles and colleagues (2013) research is the only of these studies to implement incremental doses of citric acid. Given this study identified that optimal sensitivity and specificity for VFSS and FEES were at different doses of citric acid, this could be seen as a significant variable not accounted for in the other studies. The variability in results from these studies highlight inconsistencies in approaches to CRT.

Further research by Miles and colleagues investigated CRT effectiveness in reducing pneumonia rates in the acute stroke population (Miles, Zeng, McLauchlan, & Huckabee,

2013). This randomised, controlled trial found no significant differences in pneumonia rates or mortality for patients who received CSE alone (n = 163) versus patients that underwent CSE in conjunction with CRT (n = 148). Strengths of this study include its multi-centre nature and incorporation of a standardised CRT protocol. There is, however, the potential for inconsistencies in ongoing dysphagia management administered by different clinicians across the 4 hospital sites involved. Findings suggest that use of CRT in isolation, without a consistent dysphagia management protocol, does not have an overall impact on patient outcome. Findings support the use of objective dysphagia assessment to identify aspiration risk, and also demonstrate the need for standardised dysphagia management protocols in conjunction with use of CRT.

Research led by Perry (Perry, Miles, Fink, & Huckabee, 2019) further expanded upon findings from Miles' studies. Perry and colleagues (2019) investigated the impact of a clinical management protocol incorporating CRT. Outcomes of a clinical audit of 248 stroke patients managed as per the Dysphagia in Stroke Protocol (DiSP) were compared to outcomes from the previous Miles and colleagues' (2013) study. Both cohorts of patients were recruited from the same healthcare setting. The DiSP provided a decision-making pathway to determine aspiration risk following CRT and indication for VFSS. Rates of aspiration following DiSP implementation were lower (10%) when compared to pre-DiSP rates (28%). Findings of this study suggest that simply incorporating CRT into dysphagia management is not effective in improving patient outcomes. Rather, standardising the manner in which CRT results are applied to patient care, through use of a protocol such as the DiSP, appeared to be an important factor in reducing aspiration rates in this study (Perry et al., 2019). A limitation evident in this study is the inclusion of a subjective judgement of reflexive coughing strength to determine outcomes of CRT. Clinician reliability in subjective judgment of reflexive coughing strength is known to be inconsistent (Miles & Huckabee, 2013; Miles, McFarlane, & Huckabee, 2014). The purpose of the DiSP was to improve consistency in dysphagia management. However, inclusion of a subjective coughing assessment presents the potential for variability in clinicians' perceptions of coughing strength, and therefore would increase variability in decisions about whether an individual passes or fails CRT. This highlights a limitation of CRT, which is that it does not address reflexive coughing strength or effectiveness.

### 2.4 Subjective coughing assessment

Subjective assessment of reflexive coughing strength in the clinical setting involves a clinician making a perceptual judgment about the strength of a cough as it spontaneously occurs. As in the study of the DiSP (Perry et al., 2019), coughing is commonly subjectively described as present, absent, weak or strong (Widdicombe, Addington, Fontana, & Stephens, 2011). Issues with clinician reliability in perception of reflexive coughing strength have been identified through research led by Miles (Miles & Huckabee, 2013; Miles et al., 2014). Miles and Huckabee (2013) investigated inter-rater and intra-rater reliability of clinician's subjective judgement of reflexive coughing strength during CRT. The study recruited 45 speech-language therapists, including clinicians with and without experience in CRT. Participants viewed videos of individuals undergoing CRT and rated each subsequent reflexive cough as either weak, strong or absent. Rater agreement was calculated using Fleiss' generalized kappa measurement. Overall participant agreement for strong reflexive coughing was minimal-to-weak ($\kappa$ = 0.38 - 0.49); agreement for weak reflexive coughing was minimal ($\kappa$ = 0.07 - 0.29) and absent coughing agreement was moderate ($\kappa$ = 0.63 - 0.70). Level of experience with administering CRT did not significantly improve inter-rater reliability.

Further research by Miles and colleagues (2014) investigated inter-rater reliability of speech-language therapists' subjective judgements regarding presence and strength of reflexive coughing following CRT. Fifty-eight speech-language therapists were trained in coughing physiology and strength judgement prior to viewing videos of individuals undergoing CRT. Similar to the findings of Miles and Huckabee's previous research (Miles & Huckabee, 2013), participants judgements of reflexive coughing presence were more consistent when compared to their judgments of reflexive coughing strength. Participants demonstrated moderate agreement ($\kappa$ = 0.71) in judgement of reflexive coughing presence and a weak level of agreement ($\kappa$ = 0.52) for ratings of reflexive coughing strength. Findings from both these studies demonstrate that there is inadequate clinical consensus among both experienced and inexperienced clinicians regarding their perception of reflexive coughing strength.

McCullough and colleagues also addressed the reliability of clinicians subjective reflexive coughing strength ratings in their study (McCullough et al., 2005). This research investigated the utility of CSE measures in detection of aspiration in comparison to VFSS findings with a cohort of 165 patients following acute ischaemic stroke. Inter- and intra-rater reliability was determined for elements of the CSE, including reflexive coughing strength, for a random sample of 15% of the 165 participants. If a patient demonstrated a spontaneous reflexive cough during testing, the strength and quality of this cough was rated. No information was provided about the process for ensuring consistency in identification of a reflexive cough and CRT was not used in this study. Clinicians judged reflexive coughing strength with 85% agreement and reflexive coughing quality with 92% agreement. Intra-rater reliability data was collected by completing a second CSE with the same cohort of patients the following day after the initial evaluation. Intra-rater reliability findings were not individually reported for each element of the CSE (McCullough et al., 2005).

It is acknowledged that the primary aim of McCullough and colleagues (2005) research was not to investigate the reliability of reflexive coughing strength judgements. However, reliability in this study was notably higher when compared to outcomes from research led by Miles (Miles & Huckabee, 2013; Miles et al., 2014). Limitations are evident in interpreting the results of the inter-rater reliability component of McCullough and colleagues (2005) research, which may have contributed to the higher levels of reliability. The authors do not disclose the number of reflexive coughs that occurred spontaneously in this study. Thus, the size of the samples used to determine percentage agreement of judgement of reflexive coughing strength is unknown.

A limitation present in the aforementioned studies (McCullough et al., 2005; Miles & Huckabee, 2013; Miles et al., 2014) is the use of simple categorical ratings of coughing strength, which may have restricted the breadth of participants responses. Use of a more sensitive scale, such as a visual analogue scale (VAS) would have allowed for greater variability in ratings of coughing strength. VAS is one of the most commonly used outcome measures in subjective assessment of coughing strength (Smith & Woodcock, 2008; Spinou & Birring, 2014). Benefits of the VAS include that it is simple to use, is responsive to change, and it can be used to communicate coughing severity to other clinicians for longitudinal

observation (Birring & Spinou, 2015; Smith & Woodcock, 2008; Spinou & Birring, 2014). Smith and Woodcock (2008) suggest that reliability may be an issue in methods of subjective coughing assessment, such as the VAS, due to the influence of external factors such as an individual's vigilance, mood and expectation. There is limited data published reporting on the validity of this scale in subjective assessment of coughing strength (Birring & Spinou, 2015). Current literature exploring the level of reliability of clinician's subjective ratings of reflexive coughing strength suggests that reliability is moderate to good, at best. This raises further questions about the clinical utility of subjective assessment of coughing strength, its role in clinical dysphagia management, and highlights the need for more objective coughing strength measures.

**2.5 Reflexive and voluntary coughing strength**

A major limitation in the objective assessment of both voluntary and reflexive coughing strength is that a definition of what constitutes a strong or weak cough is not clear. As previously mentioned, the terms weak and strong are routinely used in subjective clinical coughing assessment (Widdicombe et al., 2011) in order to make a judgement about the effectiveness of a cough to clear aspirated material from the airway. The assumption being made is that a strong cough provides superior clearance of aspirated material than a weak cough. However, the factor that is more clinically pertinent is whether a cough is effective at clearing aspirated material, rather than if it is strong or weak. Objective swallowing assessment allows for cough effectiveness to be determined, as an individual's ability to clear aspirated material can be visualised. Definitive information about coughing effectiveness cannot be determined on clinical assessment alone, which highlights a key limitation with subjective coughing assessment. Consequently, objective coughing parameters are often used as a proxy to define strength and to demonstrate reduced cough efficacy or aspiration risk.

When discussing coughing strength, or efficacy, a further distinction also needs to be made as to whether a cough is reflexive or voluntary in nature. Key differences between voluntary and reflexive coughing are evident in terms of neurological control, as well as aerodynamic and acoustic physiological measures. Voluntary coughing is cortically controlled and can be initiated to command (Hegland, Bolser, & Davenport, 2012). It is associated with "activation

of the primary motor and somatosensory cortices, supplementary motor area, operculum, anterior and posterior mid-cingulate cortex, insula, thalamus, basal ganglia, precuneus, inferior temporal gyri, amygdala, brain stem, and cerebellum"(Hegland et al., 2012, p. 39). In contrast, reflexive coughing is brainstem driven (Hegland et al., 2012). It can be initiated by chemical and mechanical irritation of sensory nerve fibres in the airway via a reflex response, bypassing supramedullary control and providing excitatory drive to the brainstem cough pattern generator (Mazzone, Cole, Ando, Egan, & Farrell, 2011).

It is only recently that aerodynamic and acoustic differences between reflexive and voluntary coughing have been explored. Mills and colleagues investigated strength of voluntary coughing, and supressed reflexive coughing in response to CRT (Mills et al., 2017). Data from a total of 29 healthy individuals were included for analysis, consisting of 20 females and 9 males. Participants underwent CRT elicited by inhalation of incremental doses of citric acid; they also produced voluntary coughs for analysis. Physiological measures of peak and area under the curve (AUC) for flow, pressure, and acoustics were collected for all supressed reflexive and voluntary coughs. Correlations were low between voluntary and reflexive coughing strength for all of the physiological measurements. Poor correlation was observed between acoustic measures and all other physiological measures for both reflexive and voluntary coughing.

There are some limitations to the research led by Mills (2017). In CRT, a C2 response refers to the elicitation of two successive coughs not interrupted by inspiration. Predominantly due to an absent C2 response, 24 participants in this study had to be excluded from analysis. This resulted in unequal representation of each sex (20 females and 9 males). Given acknowledged differences in coughing physiology based upon sex, equal recruitment in this study would have been beneficial. However, the study had a detailed and considered procedure to ensure consistency in collection and recording of physiological data and was the first to measure the correlation between reflexive and voluntary coughing in a healthy population (Mills et al., 2017). Findings from this study are an important addition to the current body of cough literature as they provide a strong rational for the assessment of reflexive coughing in isolation. Findings also highlight the importance of not making

inferences about the effectiveness or strength of a reflexive cough from assessment of voluntary coughing strength alone.

### 2.6 Objective assessment of coughing

Objective assessment of both voluntary and reflexive coughing parameters are often broadly categorised as either aerodynamic measures, such as peak cough flow (PCF) and peak pressure, or acoustic measures, including peak acoustic and cough sound power. Aerodynamic measures, rather than acoustic measures, are more commonly referenced in studies which investigate the relationship between objective coughing measures and swallowing efficacy. There is an under-representation of published research exploring the relationship between reflexive coughing physiological parameters and cough efficacy. Studies have been identified which explore the predictive relationship between voluntary coughing objective measures and risk of aspiration. As previously discussed, there is risk associated with making inference about reflexive coughing strength based upon voluntary coughing assessment outcomes (Mills et al., 2017). Whilst reflexive coughing provides the most appropriate representation of airway protective mechanisms, studies related to voluntary coughing have been included for discussion, despite the aforementioned limitations.

Hammond and colleagues have published multiple studies investigating the relationship between objective measures of voluntary coughing and aspiration risk in the stroke population (Hammond et al., 2009; Hammond et al., 2001). Earlier research explored whether stroke patients (n = 28) who aspirated have impaired measures of voluntary coughing when compared to both non-stroke control subjects (n = 18) and non-aspirating stroke patients (n = 15) (Hammond et al., 2001). Presence of aspiration was confirmed via either VFSS or FEES. Researchers found that all objective coughing measures were altered in the stroke group when compared to those of control subjects. Peak flow of the inspiration phase, cough volume acceleration, peak flow of the expulsive phase, expulsive phase rise time, and sound pressure level were noted to be significantly impaired in stroke patients demonstrating severe aspiration when compared to the cohort with no aspiration. Expulsive phase rise time was found to be the only measure that correlated with aspiration status.

Further research by Hammond and colleagues involved collection of aerodynamic and sound pressure level measurements of voluntary coughing immediately before or after instrumental swallowing assessment for 96 patients following ischemic stroke (Hammond et al., 2009). Expulsive phase rise time, volume acceleration, and expulsive phase peak flow were found to be sensitive indicators of aspiration risk (sensitivities of 91%, 91%, and 82%, respectively; and specificities of 81%, 92%, and 83%, respectively). Whilst authors recognise these findings still require validation, results demonstrate that objective measures of voluntary coughing have potential utility to identity those at risk of aspiration.

Bianchi and colleagues similarly focussed on voluntary coughing and aimed to retrospectively determine whether objective coughing measures can determine the risk of developing pulmonary complications (Bianchi, Baiardi, Khirani, & Cantarella, 2012). VFSS outcomes and PCF measurements from 18 dysphagic patients with persistent tracheobronchial aspiration were compared to 37 dysphagic patients without pulmonary complications. Patients with pulmonary complications demonstrated significantly lower mean PCF values compared to those without pulmonary complications. Specifically, it was observed that a PCF level below 242 litres/min predicted the development of respiratory conditions with a sensitivity and specificity of 77% and 83% respectively. Authors suggest that PCF can serve as a valuable predictor of respiratory prognosis in chronic aspiration, however application of this finding to the clinical setting should be done with caution. The retrospective nature of the study increases the risk of selection bias and it also had a relatively small sample of 18 dysphagic patients presenting with pulmonary complications. In addition, the participant population was heterogenous with aetiology of dysphagia including stroke, skull base surgery, laryngectomy and oropharyngeal reconstruction, therefore making generalisation of results to the broader clinical setting challenging.

The aforementioned studies (Bianchi et al., 2012; Hammond et al., 2009; Hammond et al., 2001) all focus on voluntary coughing, implying a reliance upon participants ability to follow commands in order to participate. This may have excluded a number of patients with neurological impairments, and potentially concurrent severe dysphagia, from participating in the studies. None of the aforementioned studies discuss the relationship between

voluntary and reflexive coughing, which has an integral role in airway clearance of aspirated material.

Ebihara and colleagues investigated impaired efficacy of both reflexive and voluntary coughing in patients with Parkinson's Disease (PD) (Ebihara et al., 2003). Twenty-five female participants with PD (15 with early stage PD and 10 with advanced stage PD) and 16 age-matched female control subjects were recruited. The mean voluntary PCF rate in patients with PD was found to be significantly weaker when compared to that of control subjects. Cough reflex sensitivity in patients with advanced PD was significantly lower than in patients with early stage PD and control subjects. This demonstrates that cough reflex sensitivity may diminish as PD progresses. Findings also suggest that PCF of voluntary coughing is a sensitive measure to demonstrate the coughing efficacy of those in the PD population at risk of dysphagia.

Limitations are evident in research led by Ebihara (2003). Authors discuss cough efficacy, however the definition of what it considered an effective cough was not provided. Rather, weaker PCF for voluntary coughing and altered cough reflex sensitivity were used as markers of efficacy (Ebihara et al., 2003). Inclusion of an instrumental swallowing assessment as a measure would have further helped to define coughing efficacy in this study. It would have been valuable to explore whether coughs deemed to have reduced PCF or diminished sensitivity were still at all effective at clearing aspirated material. Authors justify their use of only female participants due to the acknowledged differences in PCF based on sex. However, use of evenly distributed gender groups would have allowed for broader generalisation of results. Ebihara and colleagues (2003) research is however one of the few studies which encompassed assessment of both reflexive and voluntary coughing in a patient population.

Research led by Lee and colleagues also investigated physiological parameters for both reflexive and voluntary coughing (Lee et al., 2013). Authors explored the relationship between PCF for voluntary coughing and the laryngeal cough reflex (LCR) in 25 patients with traumatic brain injury (TBI) and 48 healthy controls. The LCR was elicited via CRT and then PCF was measured for each subsequent cough. PCF rates were also collected for all voluntary coughs produced by participants. The study demonstrated that voluntary PCF and

reflexive PCF were strongly related in both the control and TBI patient groups. Authors suggest that reflexive PCF has potential to estimate voluntary coughing ability in individuals who cannot participate in voluntary PCF assessment (Lee et al., 2013). Authors report to be the first to quantify LCR as a numerical value, however issues with the clinical relevance of this value are apparent. The study only investigated one objective measurement of coughing and authors do not provide normative values as a reference point for LCR measurement, making interpretation of this value challenging.

Findings from Lee and colleagues (2013) research differ in correlation strength when compared with Mills and colleagues' (2017) findings of a weak correlation between voluntary and reflexive coughing, including measurements of PCF. Lee and colleagues (2013) recruited patients with neurological impairment, as well as healthy controls, whereas Mills and colleagues (2017) focused only on healthy subjects. Research led by Mills found a low correlation between reflexive and voluntary PCF in healthy subjects (Mills et al., 2017), whereas the healthy cohort in the study by Lee and colleagues (2013) demonstrated a strong correlation between the two measures. A further difference between the studies methodologies was that Lee and colleagues (2013) used only a single dose of citric acid, in contrast research led by Mills used incremental doses. However, given that Mills and colleagues (2017) state that that citric acid dose did not have a significant effect on reflexive coughing strength, the differences in dosages does not appear to be a factor that significantly influenced the outcome of results. The reason for the different outcomes in these two studies remains unclear, but it does suggest that the relationship between voluntary and reflexive PCF requires further attention. The findings of Mills and colleagues (2017) are more robust by comparing six different physiological parameters, rather than PCF alone; thus providing a broader insight into objective coughing assessment.

Results from the aforementioned studies suggest that there is potential for objective aerodynamic voluntary coughing measures to be clinical indicators of aspiration risk and assist in identifying patients that require objective swallowing evaluation. Expulsive phase rise time (Hammond et al., 2001) (Hammond et al., 2009), volume acceleration (Hammond et al., 2009) and PCF were all found to be sensitive indicators of aspiration risk. PCF was a common measure which was present in multiple studies (Bianchi et al., 2012; Ebihara et al.,

2003; Hammond et al., 2009; Lee et al., 2013) which suggests it is a sensitive physiological measure to demonstrate aspiration risk and voluntary cough efficacy. A further explanation for its frequent inclusion in studies is that PCF is viewed as one of the most practical objective measures, as it is an easily performed, non-invasive measurement (Spinou & Birring, 2014).

Feinstein and colleagues established voluntary coughing normative values for PCF, peak pressure and expiratory rise time with a sample 29 women and 23 men (Feinstein, Zhang, Chhetri, & Long, 2017). Differences in coughing aerodynamics based on sex were evident in this study. PCF and cough peak pressure were noted to be lower in females. Expiratory rise time was the most consistent coughing parameter, as it did not vary with height or age, however it was significantly longer in women. PCF and cough peak pressure were also noted to rise with increasing height (Feinstein et al., 2017). This demonstrates the importance of categorising participants by age, sex and height in future cough measurement studies. Findings provide important normative voluntary coughing data for a healthy population which is crucial in defining the future utility of objective coughing assessment. This study did not determine numerical cut-offs, or definitions for weak and strong coughing, however its findings add to the discussion about what constitutes normal coughing parameters. Outcomes of objective coughing assessments may have potential to be compared against population norms to help identify coughing dysfunction, again this is an area that requires further research. Whilst this study focussed on voluntary coughing, it raises the potential for establishment of normative values for reflexive coughing.

Feinstein and colleagues suggest that assessment of coughing strength is currently not a "routine aspect of care because basic cough mechanisms remain poorly understood" (Feinstein et al., 2017, p. 396). Findings from the aforementioned studies similarly suggest that further research needs to be undertaken before objective assessment of coughing strength has clinical utility. Studies do however demonstrate potential for objective measures, such as voluntary PCF, to identify aspiration risk. Until further research into objective coughing assessment is undertaken, subjective assessment will continue to be used in the clinical setting. Issues with reliability of subjective assessment of reflexive coughing strength have been well documented (Miles & Huckabee, 2013; Miles et al., 2014).

An area of reflexive coughing assessment which has had limited focus is the validity of clinician's subjective strength ratings, through comparison with objective coughing measures.

**2.7 Relationship between perceptual and objective assessment of coughing**

There is heterogeneity among the few studies that investigate the relationship between perceptual and objective assessment of coughing. Whilst existing studies investigate the relationship between subjective voluntary coughing assessment and physiological parameters, there is no previous research that focussed on reflexive coughing to explore this relationship. Reflexive coughing would intuitively be a more representative assessment of aspiration risk and coughing efficacy given its role in airway protection. However, in the absence of this research, studies related to voluntary coughing have been reviewed.

Lee and colleagues investigated the intensity of induced, voluntary, and spontaneous coughing in 28 patients with chronic cough and 21 healthy control subjects (Lee, Ward, Rafferty, Moxham, & Birring, 2015). Objective assessments included measurement of gastric pressure and oesophageal pressure, PCF, expiratory muscle strength, and cough compression phase duration. It was found that coughing intensity is increased in patients with chronic cough compared to control subjects, likely as a result of an increase in expiratory muscle strength. They also found that gastric pressure, oesophageal pressure and PCF were significantly greater in individuals with chronic cough compared to healthy subjects. The subjective component of this study involved patients rating the intensity of 10 voluntary coughs on a VAS from 1 to 100. The median correlation coefficient between coughing intensity VAS ratings and PCF was 0.82, suggesting a strong relationship between the two variables (Lee et al., 2015). Given this study involved patients as raters, and the sample of coughs being rated was small, the results of the subjective aspect of this study are difficult to generalise to the clinical setting in terms of clinical assessment of coughing strength.

A more recent study by Lee and colleagues similarly recruited patients to provide perceptual ratings of coughing strength. This study investigated the relationship between voluntary coughing sound measures and physiological measures of coughing strength in 17 patients

with chronic cough and 15 healthy controls (Lee et al., 2017). Standardised recording approaches were used to ensure consistency among cough samples. Coughing sound parameters included peak energy, rise time, duration, power, peak frequency, centroid frequency and bandwidth. Of all the coughing sound parameters measured in the study, cough sound power and cough peak energy had the strongest association with PCF (r = 0.87 - 0.88). This is in contrast to findings from Mills and colleagues (2017) of a poor correlation between voluntary PCF and acoustic measures, including peak acoustic (r = 0.29) and AUC acoustic (r = 0.29). A key difference between these studies is that Mills and colleagues (2017) studied a healthy population, whereas Lee's research included both healthy participants and individuals with chronic cough (Lee et al., 2017). Lee and colleagues (2017) also included a wider variety of coughing sound measures for analysis, in comparison to Mills' research which focussed only on peak and AUC acoustic measures (Mills et al., 2017). These methodological differences could be a factor which contributed to the differing correlations between acoustic and aerodynamic measures in the two studies. Findings from Lee and colleagues (2017) highlight potential for a relationship between coughing aerodynamic and acoustic measures. However, at present the inconsistencies in results from these two studies suggest that there is currently insufficient evidence to justify the use of acoustic cough measures in clinical coughing assessment.

Lee and colleagues also investigated subjective patient ratings of voluntary coughing. Eight participants produced at least 10 single voluntary coughs and then rated the strength of each cough on a 100-point VAS (Lee et al., 2017). The correlation for judgements of coughing strength were strongest for cough sound power (r = 0.84) and cough peak energy (r = 0.86). Cough sound power and cough peak energy had the strongest correlation with coughing strength on both the objective and subjective components of this study. Findings from this study suggest that cough sound measures may have a relationship with subjective assessment of coughing strength.

In contrast, Smith and colleagues recruited health professionals to explore the relationship between perceptual coughing assessment and acoustic properties of spontaneous coughing sounds (Smith, Ashurst, Jack, Woodcock, & Earis, 2006). Specifically, investigating how health care professionals describe coughing sounds, identify basic sound qualities of coughing and whether they can identify a diagnosis solely from coughing sounds. The study

sampled 53 participants from backgrounds including respiratory physicians, physiotherapists and specialist respiratory nurses. The qualities of each of the cough samples were first assessed by experienced researchers and then confirmed using acoustic sound analysis. Approximately three quarters of participants (76%) could correctly differentiate between a cough with or without mucus. Clinicians were less reliable at identifying a cough with wheeze (39%) and were also not reliable in their ability to identify clinical diagnosis from a single cough (34%). The findings of Smith and colleagues (2006) of limited correlations between experienced clinicians' perceptual ratings of coughing qualities and acoustic sound analysis further highlights the clinical futility of using perceptual judgements to determine the quality or effectiveness of a cough.

Laciuga and colleagues also investigated clinicians' perceptions of voluntary coughing characteristics (Laciuga, Brandimore, Troche, & Hegland, 2016). This study aimed to determine whether voluntary coughs with specific airflow characteristics shared common perceptual descriptions. Thirty experienced clinicians who routinely assess coughing function were recruited, including speech-language therapists, otolaryngologists and neurologists. Voluntary coughs that were perceived as strong and effective were found to share distinctive parameters, including high values of peak expiratory flow rate (PEFR), cough volume acceleration (CVA) and total expired volume (TEV) (Laciuga et al., 2016). Coughs perceived as weak and ineffective had low values in at least one of the following parameters: PEFR, TEV or CVA. Whilst common parameters were identified for both strong and weak coughing, participants only had moderate agreement in assessing coughing strength, effectiveness and duration. The greatest inconsistencies in ratings were noted in the clinician's perceptions of coughing quality. As a result, Laciuga and colleagues (2016) suggest that perceptual assessment of voluntary coughing may not be sufficient to determine the integrity of airway protection.

A limitation of this study relates to the manner in which the coughing samples were collected. Members of the research team produced specific coughs under different criteria so that a variety of voluntary coughing examples could be used for ratings (Laciuga et al., 2016). 'Natural' coughing samples were not used, which raises potential for bias, and means that the coughing samples participants rated were not necessarily representative of the clinical setting. In addition, only 10 cough samples were used in this study, which may not

be a larger enough number to demonstrate a relationship between subjective ratings and objective parameters. Despite this, participants in this study had recognised skills and experience in coughing assessment. Therefore, results of this study have merit when considering the accuracy of clinician's perceptions of coughing characteristics. Both Laciuga and colleagues (2016), and research led by Smith (2006), found inconsistencies in clinicians' perceptions of coughing qualities when compared to acoustic (Smith et al., 2006) and aerodynamic physiological parameters (Laciuga et al., 2016). This further brings into question the validity of subjective coughing assessment and its utility in determining coughing strength and efficacy.

### 2.8 Study aims

Whilst there is a growing body of evidence investigating the utility of objective and subjective assessment of voluntary coughing strength, there is a lack of studies demonstrating the validity of strength assessment of reflexive coughing. No previous research has been identified which examines the relationship between perceptual ratings of reflexive coughing strength and objective coughing measures. Laciuga and colleagues investigated the relationship between clinicians perception of coughing characteristics and objective coughing measures; however, this study focussed on voluntary coughing alone (Laciuga et al., 2016). Miles and colleagues reliability studies demonstrated that clinicians agreement in rating of reflexive coughing strength is only moderate at best (Miles & Huckabee, 2013; Miles et al., 2014). These studies did not explore the relationship between the clinician's ratings of reflexive coughing strength and objective coughing measures. The present study seeks to investigate the relationship between objective coughing measures of peak pressure, peak flow and peak acoustic, and clinicians' perceptual ratings of reflexive coughing strength in healthy individuals. Both acoustic (peak acoustic) and aerodynamic measures (peak flow and peak pressure) have been included to allow for a broad comparison of physiological coughing parameters. Clinician inter- and intra-rater reliability regarding perception of reflexive coughing strength will also be investigated. It is hypothesised that reflexive coughs with specific physiological characteristics would share common subjective ratings of strength.

## 3. Methodology

This study investigated inter-rater and intra-rater reliability of clinician perception of reflexive coughing strength, and the relationship between clinician perceptual ratings of strength and objective coughing measures of peak pressure, peak flow and peak acoustic.

### 3.1 Participants

Inclusion criteria for this study specified that participants must be either a speech-language therapist or a speech-language therapy student**.** Participants were recruited to the study via existing professional networks (see Appendix 1) and through use of social media (see Appendix 2). A power calculation was undertaken using a mixed-effect logistics regression based on pilot study data collected by Mills and colleagues to determine the number of participants required for this study (Mills et al., 2017). This pilot study was completed using binary strength ratings of weak and strong. The present studies' strength ratings are based on a more sensitive VAS with a minimum of 50 participants required to achieve a power of at least 80% for the inter-rater aspect of the study. This study was granted approval by the University of Canterbury Human Ethics Committee.

### 3.2 Materials

#### 3.2.1 Video recordings

Video recordings and physiological data used in this study were originally collected in research completed by Mills and colleagues (2017). Authors investigated the relationship between both voluntary and suppressed reflexive coughing strength, elicited by inhalation of incremental doses of citric acid, and outcome measures of airflow, pressure, and acoustics. Mills and colleagues (2017) collected a total of 105 individual video recordings of healthy individuals producing a reflexive cough whilst undergoing CRT. Physiological measures of peak and AUC for flow, pressure, and acoustics were collected for all supressed reflexive and voluntary coughs. Participants were both male and female and aged between 50 to 84. All participants gave informed consent for their videos to be used for teaching and research purposes (Mills et al., 2017).

### 3.2.2 Video selection

Thirty-six videos were selected from the sample of 105 to be used in the inter- and intra-rater reliability study. These 36 coughs represented the six coughs with the highest and lowest values from each of the categories of peak flow, pressure and acoustic. Values from the extreme ends of the sample data were selected to allow for greater distinction and variety between the samples. Videos were edited using iMovie for Mac (Apple, Cupertino, CA). Videos ranged between 2 seconds and 14 seconds in length.

### 3.2.3 Online survey

Video clips were compiled into an online survey using the Qualtrics Survey platform (Qualtrics, Provo, UT). Qualtrics software had the capability to store videos in a confidential manner that could be easily accessed online by participants. Videos were organised in a random sequence in the Qualtrics Survey platform.

## 3.3 Procedure

Participants were recruited to the study via existing professional networks and via social media, including specialist speech-language therapist professional group pages. Participants were provided with a hyperlink to an online version of the participant information sheet, along with further details about the study (see Appendix 3). At the end of the information sheet, participants were informed that continuing on to the survey would imply consent to participate. Following completion of the inter-rater reliability study, participants were subsequently invited to complete the intra-rater component of the study at a later time.

Consenting participants were required to complete two anonymous online surveys. Upon commencement, participants were provided with a brief overview of the purpose of the research and demographic data were collected. Demographic data included participant's position (clinician/student), years of clinical practice experience in both CRT and dysphagia management, and area of clinical expertise. Before commencing the study, participants listened to a white noise recording and were instructed to adjust the volume of their computer to a comfortable perceptual listening level. Participants were instructed not to adjust volume for the remainder of the survey.

Initial instructions for survey completion were provided and participants were shown anchor videos representing a strong and a weak reflexive cough. Anchor videos included the two coughing samples that recorded the highest and lowest peak acoustic values. Peak acoustic was chosen as the measure for the example video as this was an auditory perceptual study, therefore an acoustic measure was deemed to have the greatest relevance. These anchor videos served as a benchmark to guide participants' ratings as to what is considered a strong and a weak cough.

Participants completed Survey One (inter-rater reliability) (see Appendix 4) in which they responded to demographic questions and rated their perception of reflexive coughing strength for each of the 36 videos on a 100-point VAS from weak to strong (see Figure 1). Participants were then requested to return to complete Survey Two (intra-rater reliability) after a period of at least 3 days following the completion of Survey One. Participants were required to develop a unique code and enter the same code into each study to allow investigators to anonymously pair responses for Survey One and Two. Survey Two required participants to again listen to the white noise recording to stabilise volume for the survey. Participants then viewed the same 36 re-randomised videos and rated reflexive coughing strength for each of the videos on the same 100-point VAS from weak to strong.

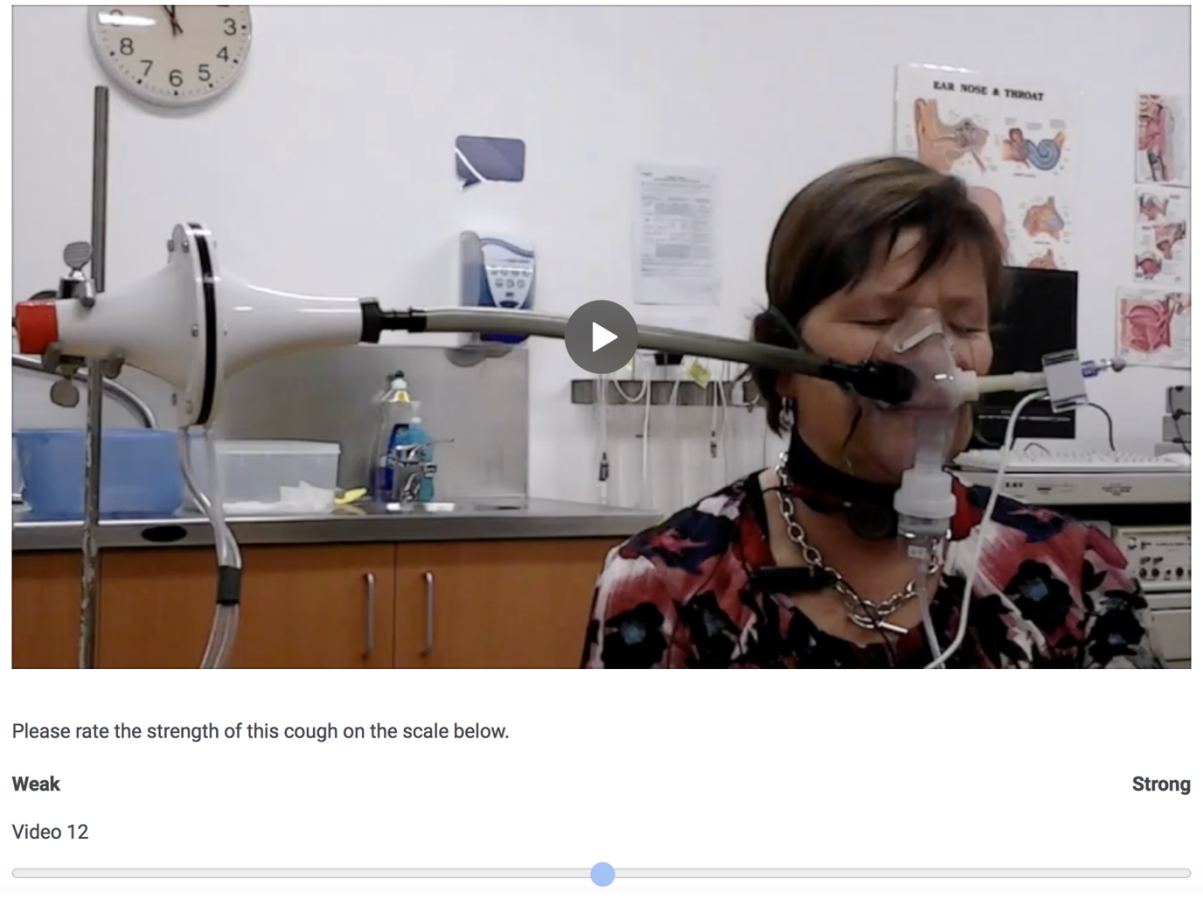


*Figure 1.* Example of video depicting an individual undergoing CRT and 100-point VAS

### 3.4 Statistical analysis

Responses to demographic questions and participants VAS ratings were extracted from Qualtrics in an Excel spreadsheet (Microsoft, Redmond, WA) for analysis. Data were exported into R Project for Statistical Computing (R Foundation for Statistical Computing, Vienna, Austria). Demographic data were recorded, and participants grouped by level of experience.

Both inter- and intra-rater reliability were calculated using an Intraclass Correlation Coefficient (ICC). To calculate the ICC a linear mixed effects model was applied to the data. In the model, an intercept only was entered as a fixed effect and a random intercept by rater and a random intercept by cough video were entered as a random effect. The inter-rater ICC was calculated by dividing the variability between clips, by the total variability (residuals variability + between cough video variability + between raters variability).

The intra-rater reliability was calculated using the same model as inter-rater reliability, but the ICC coefficient was calculated by adding the variance between cough videos to the variance between raters, then dividing it by the total variance (residuals variability + between cough video variability + between raters variability). This ICC reflects the correlation between two randomly selected observations that share both the same cough video and the same rater (intra-rater observations).

The scale discussed by Portney and Watkins was used to assess the ICC coefficients (Portney & Watkins, 2013). This scale suggests that ICC values greater than 0.75 indicate good reliability, values less than 0.75 indicate poor to moderate reliability and that "reliability should exceed 0.90 to ensure reasonable validity" (Portney & Watkins, 2013, p. 604). In addition to ICC, standard deviation (SD) between coughs was reported to provide further detail about variation in the sample.

The relationship between participants' VAS ratings and the physiological measure was explored for the 36 coughs. The association between VAS score and each physiological measure was determined using a correlation test. The criteria outlined by Portney and Watkins (2013) was used to assess the strength of any correlation determined. The Portney and Watkins (2013) guideline suggests that correlation coefficients between 0.00 to 0.25 indicate little or no relationship, 0.25 to 0.50 suggests a fair relationship, 0.50 to 0.75 indicative of a moderate to good relationship and above 0.75 represents a good to excellent relationship.

The difference in physiological measures between male and female video subjects was explored to consider the impact that sex may have had on participant ratings of coughing strength. In order to compare VAS scores and physiological measures between males and females, an independent-samples t-test will be used.

## 4. Results

A total of 82 participants consented to participate in the study, provided responses to demographic questions and completed ratings for the inter-rater reliability component. Thirty-six participants elected to additionally provide ratings for intra-rater reliability analysis. A further three participants completed only Survey Two and did not provide responses to Survey One or demographic questions. Responses from these participants were excluded from the analysis.

### 4.1 Demographic data

Demographic data from the 82 participants were collected and qualitatively analysed for themes and commonalities.

*Years of post-graduate clinical experience*

Practicing clinicians represented the majority (80%) of participants in this study, versus 20% (17) of participants identifying as students. Respondents were mostly experienced clinicians, with 76% having greater than 5 years of postgraduate experience, and 31% having more than 15 years' experience. Inexperienced clinicians comprised the minority, with 9% reporting two or less years of experience and 15% reporting 2 to 5 years' experience (as shown in Figure 2).

*Experience administering CRT*

Of the 82 participants, 55 (67%) reported having no experience with CRT. The remaining 27 participants (33%) identified as having some level of experience with administering CRT. Among participants with experience in CRT, almost half (48%) reported having up to 1 year of experience administering CRT. A minority of respondents had more extensive experience in CRT: 22% with 2 years' experience, 4% with 3 years' experience, 4% with 4 years' experience and 22% having greater than 5 years' experience.

*Experience with dysphagia management*

Participants were experienced in dysphagia management; with 60% reporting greater than 5 years' experience, and 22% reporting greater than 15 years' experience. Table 1 outlines dysphagia management experience in all participants and also the subset of participants with experience in CRT.

| YEARS OF DYSPHAGIA MANAGEMENT EXPERIENCE | TOTAL PARTICIPANTS | PARTICIPANTS WITH CRT EXPERIENCE |
|---|---|---|
| STUDENT | 16 | 3 |
| 0 – 2 YEARS | 6 | 5 |
| 2 – 5 YEARS | 11 | 4 |
| 5 – 10 YEARS | 21 | 8 |
| 10 – 15 YEARS | 10 | 3 |
| >15 YEARS | 18 | 4 |
| **TOTAL** | **82** | **27** |

*Table 1.* Years of postgraduate dysphagia management experience of those participants that have experience with CRT

*Area of clinical practice*

Participants identified as working across a variety of areas of clinical practice. The highest cohort of respondents came from the acute care setting. Figure 2 provides further detail about participants areas of clinical practice.

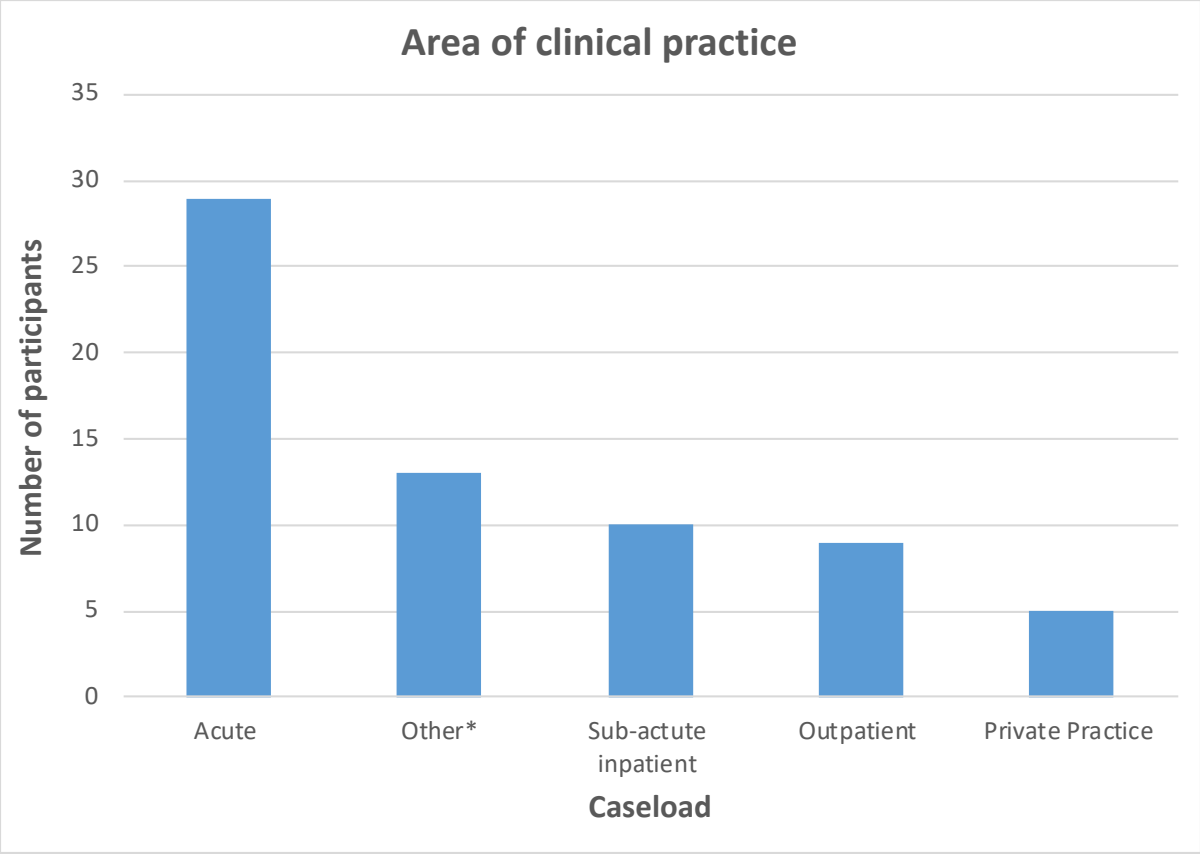


*Figure 2.* Participants area of clinical practice. *Other includes academia, clinical research, skilled nursing, hospice or having a combination of inpatient and outpatient caseloads

**4.2 Variability of VAS ratings for reflexive coughing**

Participants provided a range of different ratings of reflexive coughing strength for each of individual 36 cough selected for analysis. The overall VAS mean was 49.77 (SD = 33.46) with the VAS mean ranging from 5.38 – 89.83 for the 36 coughs. Additional VAS mean, range and SD for each individual cough can be found in Appendix 5 with corresponding physiological measures. The mean VAS rating for participants experienced with CRT was 48.44 (SD = 32.82) and for those with no CRT experience the mean VAS rating was 50.43 (SD = 33.77).

**4.3 Inter-rater reliability**

Inter-rater reliability was determined using ICC for 82 participants rating the 36 video clips, as shown in Table 2. Moderate (0.67) reliability between participants was evident, which did not appear to be influenced by experience with CRT. Inter-rater agreement regarding the rating of reflexive coughing strength for participants experienced with CRT was moderate

(0.66). Inter-rater agreement regarding the rating of reflexive coughing strength for participants with no experience was also moderate (0.68). Comparison of ratings from participants with experience in CRT versus ratings from participants with no experience in CRT demonstrate similar reliability.

| | | ICC [95% CI] | Between coughs SD [95% CI] |
|---|---|---|---|
| **Inter-rater reliability** | **CRT experience (N:27)** | 0.66 [0.53, 0.75] | 27.28 [21.63, 34.69] |
| | **No CRT experience (N:55)** | 0.68 [0.55, 0.77] | 28.45 [22.60, 36.10] |
| | **Combined group (N:82)** | 0.67 [0.54, 0.76] | 28.09 [22.32, 35.62] |
| **Intra-rater reliability** | **CRT experience (N:12)** | 0.72 [0.60, 0.79] | 27.29 [21.65, 34.76] |
| | **No CRT experience (N:24)** | 0.72 [0.60, 0.79] | 29.20 [23.19, 37.06] |
| | **Combined group (N:36)** | 0.72 [0.60, 0.79] | 28.58 [22.71, 36.25] |

*Table 2.* Intra- and inter-rater reliability for participants with experience in CRT, participants with no experience in CRT and combined reliability for both groups

### 4.4 Intra-rater reliability

Intra-rater reliability was determined using ICC for 36 participants rating the 36 video clips, as shown in Table 2. Overall intra-rater agreement for reflexive cough strength was moderate (0.72). Intra-rater reliability for reflexive coughing strength for participants experienced with CRT was moderate (0.72). Intra-rater reliability for reflexive coughing strength for participants with no experience with CRT was also moderate (0.72). Ratings from participants with experience in CRT versus ratings from participants with no experience in CRT demonstrated the same level of reliability (Table 2).

### 4.5 Correlation between physiological variables and VAS score

Since the normality assumption was not met, a Kendall's tau-b correlation was used to determine the relationship between VAS scores and physiological measures. The average VAS score across all raters was used for this calculation. There was no association between VAS score and peak flow ($\tau_b$ (81) = 0.18, p = 0.13). Similarly, no association was determined

between VAS score and peak acoustic ($\tau_b$ (81) = 0.17, p = 0.14). A moderate positive association was present between VAS score and peak pressure ($\tau_b$ (81) = 0.46, p <0.01).

There was no association between VAS score and peak flow for both participants with CRT experience ($\tau_b$ (26) = 0.19, p = 0.10) or those with no CRT experience ($\tau_b$ (54) = 0.17, p = 0.15). Likewise, there was no association between VAS score and peak acoustic for both participants with CRT experience ($\tau_b$ (26) = 0.18, p = 0.09) and participants with no CRT experience ($\tau_b$ (54) = 0.18, p = 0.14). A moderate positive association between VAS score and peak pressure was evident for both participants with CRT experience ($\tau_b$ (26) = 0.48, p <0.01) and participants with no CRT experience ($\tau_b$ (54) = 0.45, p <0.01). Figures 3 - 5 demonstrate the differences in correlation between participants average VAS scores and each physiological measure based upon CRT experience level.

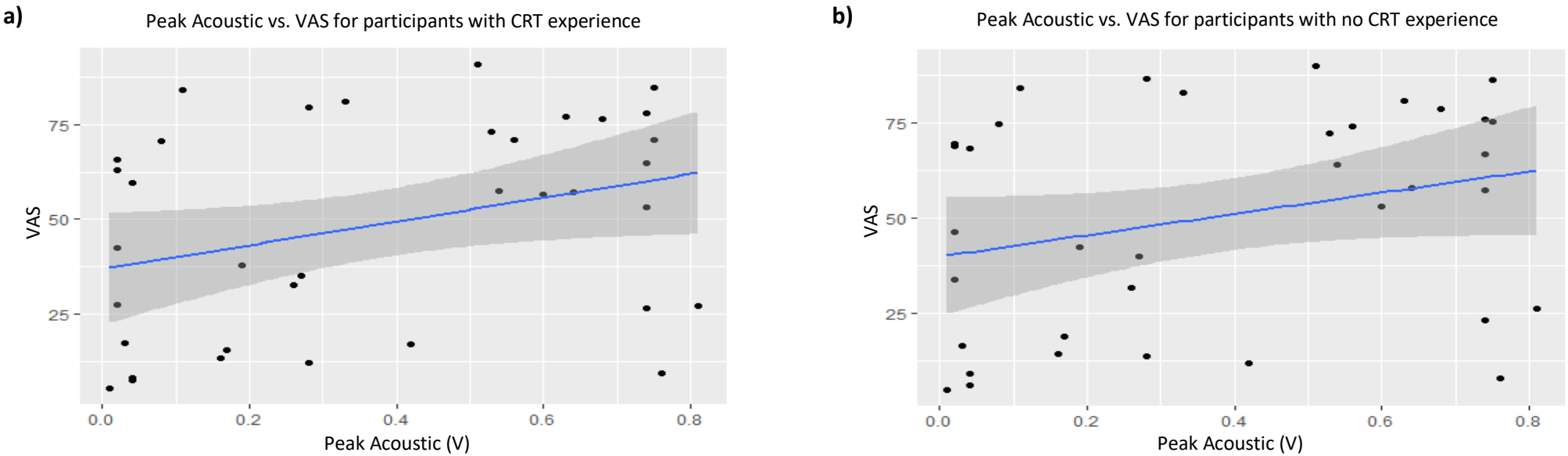


*Figure 3. a)* Averaged VAS scores vs acoustic values for participants experienced in CRT, *b)* Averaged VAS scores vs acoustic values for participants with no experience in CRT

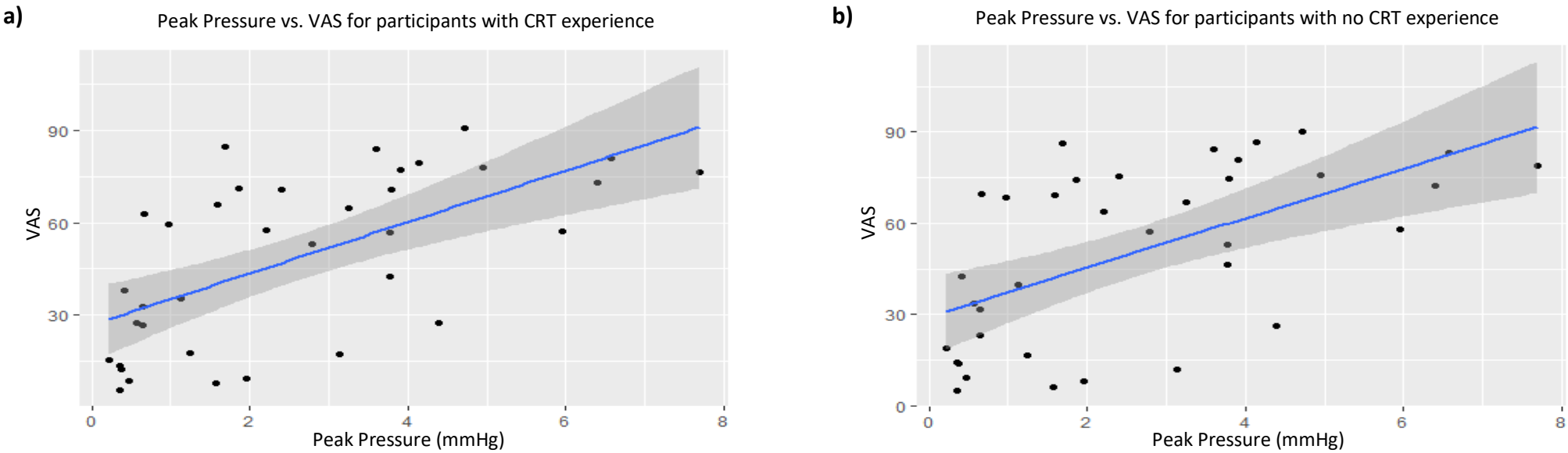


*Figure 4. a)* Averaged VAS scores vs pressure values for participants experienced in CRT, *b)* Averaged VAS scores vs pressure values for participants with no experience in CRT

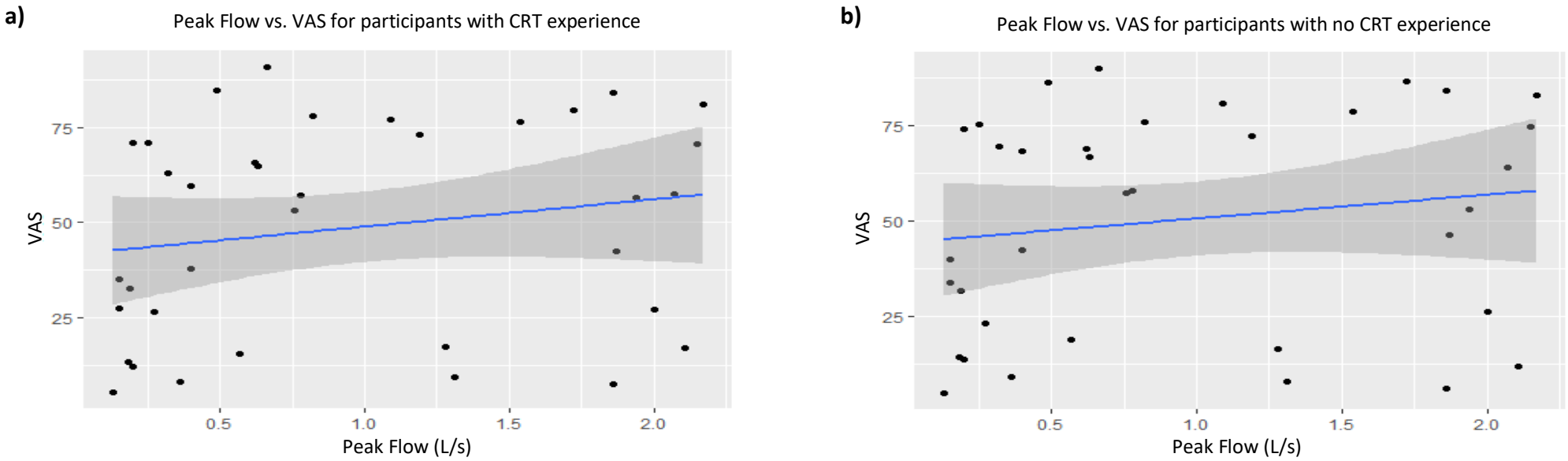


*Figure 5. a)* Averaged VAS scores vs flow values for participants experienced in CRT, *b)* Averaged VAS scores vs flow values for participants with no experience in CRT

**4.6 VAS mean and range ordered by peak pressure, peak flow and peak acoustic**

Figures 6 - 8 provide a visual representation of the association between VAS scores and physiological measures. The 36 individual reflexive coughs ranked from lowest physiological value to highest, which are transposed over the VAS mean and range for each cough. The individual cough number is provided on the x-axis. Figure 6 demonstrates that level of peak pressure does not consistently dictate VAS rating of coughing strength. However, there is more alignment between clinician ratings of extreme values of peak pressure and VAS. Figure 7 demonstrates no substantial alignment between peak flow and VAS strength rating at either higher or lower values. Whilst the correlation between peak acoustic and average VAS score is not significant, Figure 8 demonstrates that there is potentially slightly more alignment between higher peak acoustic values and VAS strength rating.

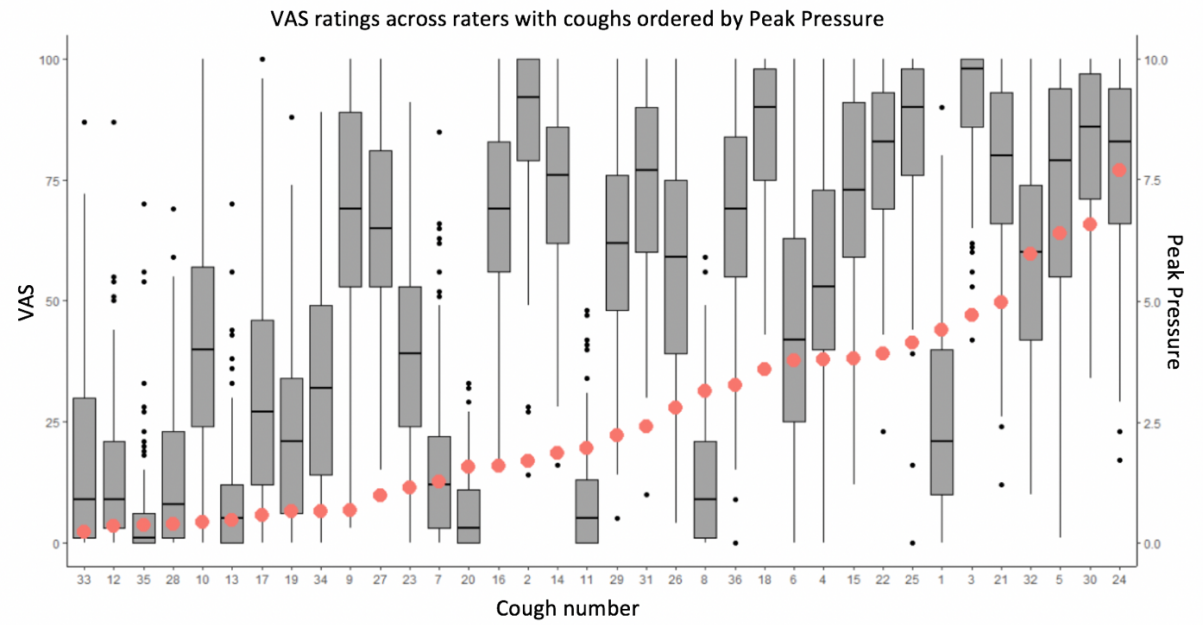


*Figure 6.* VAS mean and range ordered by peak pressure values

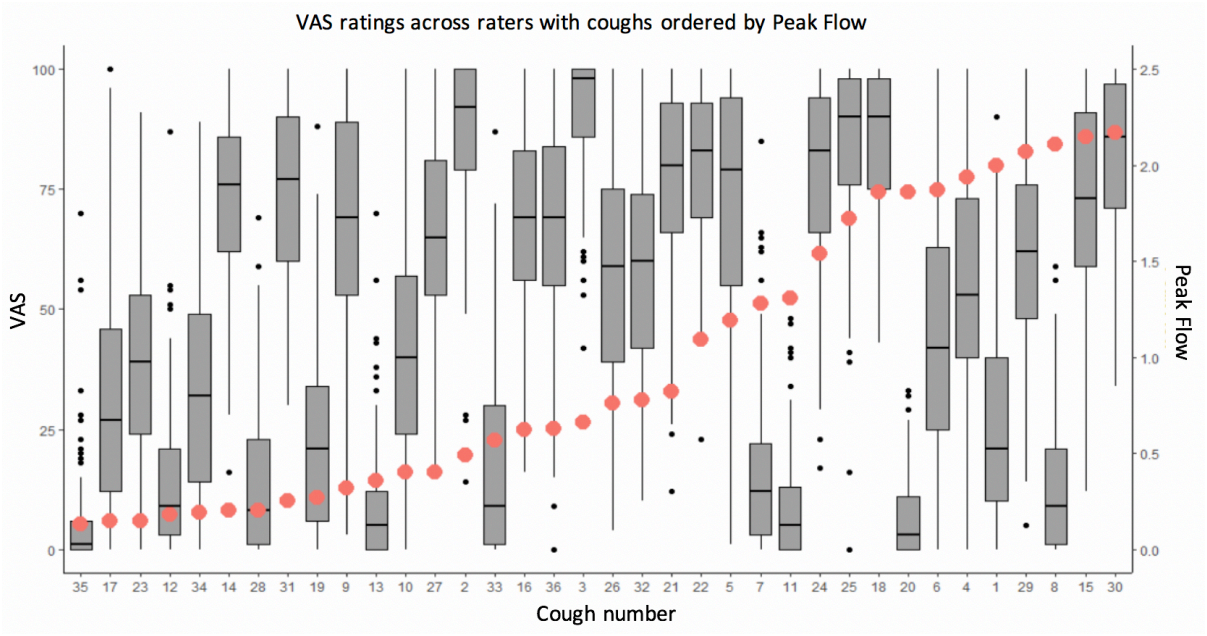


*Figure 7.* VAS mean and range ordered by peak flow values

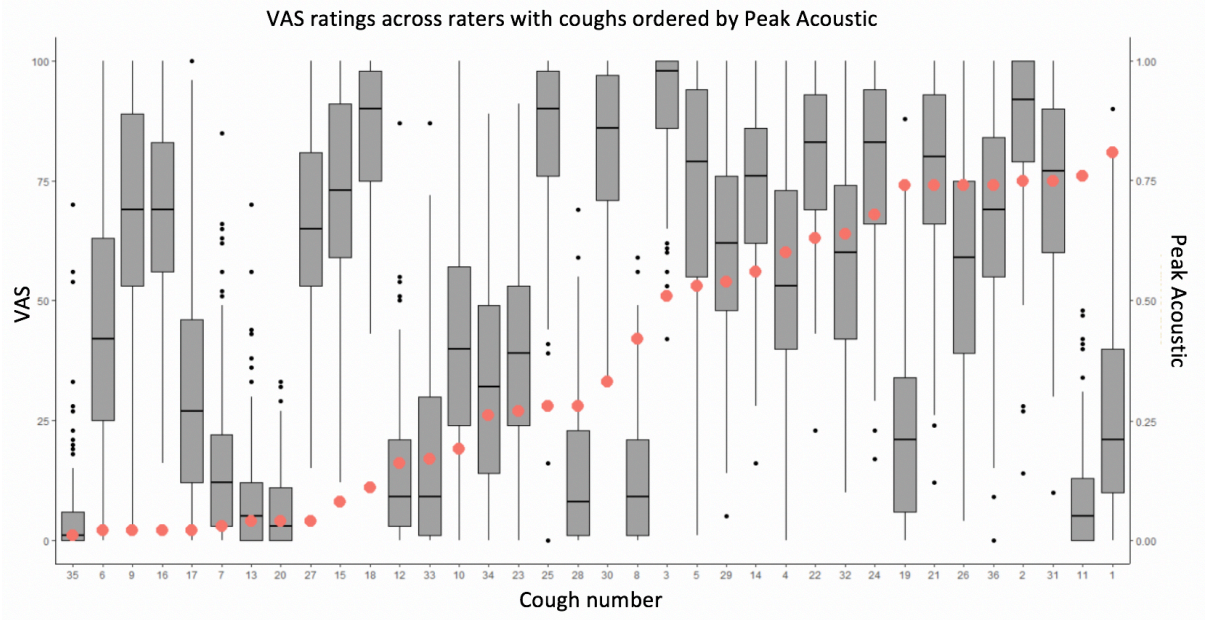


*Figure 8.* VAS mean and range ordered by peak acoustic values

### 4.7 Sex and reflexive coughing physiology

The mean and SD for VAS and each physiological measure based on sex can be observed in Table 3. Four independent-samples t-tests were conducted to compare VAS scores and physiological measures between males and females. There was no significant difference in the VAS scores as a function of sex (t*VAS*(34) = 0.29, p = 0.78). There was a significant sex difference in each of the physiological variables with a higher value for males in all cases [t*peakpressure* (34) = 2.56, p = 0.02; t*peakflow* (34) = 2.52, p = 0.02; t*peakacoustic* (34) = 2.29, p = 0.03].

| | | **VAS** | | **Peak Pressure (mmHg)** | | **Peak Flow (L/s)** | | **Peak Acoustic (V)** | |
|---|---|---|---|---|---|---|---|---|---|
| | **n** | **mean** | **SD** | **mean** | **SD** | **mean** | **SD** | **mean** | **SD** |
| **Female** | 24 | 48.99 | 29.42 | 2.04 | 1.62 | 0.76 | 0.68 | 0.30 | 0.30 |
| **Male** | 12 | 51.90 | 26.33 | 3.76 | 2.39 | 1.37 | 0.69 | 0.52 | 0.22 |

*Table 3.* Mean and standard deviation for VAS and each physiological measure based on sex.

## 5. Discussion

This is the first study to investigate the relationship between acoustic and aerodynamic measures of peak acoustic, peak flow and peak pressure, and clinicians' perceptual ratings of reflexive coughing strength in healthy individuals. Participant inter- and intra-rater reliability regarding perception of reflexive coughing strength were also evaluated.

### 5.1 Clinician reliability in perceptual rating of reflexive coughing strength

Perceptual judgements of reflexive coughing strength are routinely made in the clinical setting and can influence decisions regarding dysphagia management. This study demonstrated that clinician inter-rater agreement regarding perception of reflexive coughing strength is only moderate. This finding is consistent with previous studies investigating inter-rater reliability of clinician's perceptions of reflexive coughing strength elicited via CRT. Miles and Huckabee's initial reliability study demonstrated fair-to-moderate agreement for clinicians ratings of strong reflexive coughing and slight-to-fair agreement for ratings of weak reflexive coughing (Miles & Huckabee, 2013). A further study from Miles and colleagues demonstrated moderate agreement in clinicians ratings of reflexive coughing strength (Miles et al., 2014). Both these studies only allowed participants the binary options of weak or strong ratings to describe each cough, whereas the present study implemented a 100-point VAS. In theory, the VAS should allow for a broader range of strength ratings and greater variability among participants judgments of coughing strength. However, despite the potential for greater variability in ratings with use of the VAS, the present study achieved comparable inter-rater reliability.

In contrast, McCullough and colleagues reported 85% agreement regarding clinician judgement of reflexive coughing strength (McCullough et al., 2005), which is a greater level of agreement compared to the aforementioned studies. Participants in this study were from a patient population, where the range of coughing is likely broader and thus may have influenced findings. It should also be noted that this study did not report the sample size on which this calculation was based, which may explain the greater level of agreement amongst ratings of reflexive coughing strength.

Participants in the present study demonstrated moderate intra-rater reliability regarding their perception of reflexive coughing strength. Lower intra-rater reliability levels were calculated when compared to Miles and Huckabee's (2013) finding of substantial agreement among participants. Once again, the use of binary responses of "weak" and "strong", rather than a 100-point VAS, may account for this difference. Restricted binary options for strength ratings may have resulted in greater agreement amongst participants when compared to the greater variability in rating options available with the VAS.

### 5.1.1 Impact of experience with CRT on reliability

Experience with CRT did not influence reliability of perception of reflexive coughing strength. Inter-rater reliability for participants with experience with CRT and participants with no experience with CRT was comparable, with both groups achieving moderate reliability. Miles and Huckabee (2013) found marginally improved inter-rater reliability for participants with CRT experience when compared to those with no experience. Inter-rater reliability for experienced raters was moderate and inter-rater reliability for inexperienced raters was fair-moderate. A further study by Miles and colleagues (2014) found inter-rater agreement regarding perception of reflexive coughing strength was fair for individuals with experience in CRT (n = 9) and moderate for those with no experience in CRT (n = 49). Whilst this study further highlights inconsistencies with clinicians' perception of coughing strength, the imbalance in the sample size of the two cohorts needs to be taken into account when interpreting this finding.

Similar to inter-rater reliability findings, experience with CRT did not influence intra-rater reliability. Clinicians with CRT experience, and those with no experience, both achieved moderate reliability. Miles and Huckabee's (2013) study discusses slightly improved intra-rater reliability in their cohort of participants with experience in CRT compared to those without. However, this difference is marginal and still places both groups within the category of substantial agreement. The present study also found that mean VAS scores were comparable for clinicians with CRT experience and those without experience. These results suggest that experience in CRT does not translate into clinicians having a greater level of reliability in their judgements of reflexive coughing strength.

In summary, the need for accuracy in perceptual judgments of reflexive coughing strength is essential. These conclusions can influence recommendations regarding the provision of diet and fluids; and can also contribute to a diagnosis of dysphagia. Findings from this study, and similar reliability studies, demonstrate inconsistency in clinicians' perceptual ratings of reflexive coughing strength. Furthermore, experience with CRT did not influence clinician inter- and intra-rater reliability levels. In a clinical context, it is concerning that there is only a moderate level of agreement amongst clinicians regarding judgement of reflexive coughing strength. These judgements are a key part of the CSE in terms of building a clinical picture about an individual's ability to protect their airway in the event of aspiration. Inconsistencies in clinicians' ratings of reflexive coughing strength further draw into question the role of subjective assessment of coughing strength in the clinical setting. Findings highlight the need for the CSE to be supplemented by objective swallowing assessment to more accurately assess an individual's risk of aspiration.

### 5.2 Relationship between perceptual assessment and objective coughing measures

The relationship between average mean VAS score and the variables of peak pressure, peak flow and peak acoustic was explored to determine the validity of clinicians reflexive coughing strength ratings.

#### 5.2.1 Aerodynamic coughing features

In the present study, clinicians' perceptions of reflexive coughing strength were not validated by objective aerodynamic coughing measures, specifically peak pressure and peak flow, if these are considered the gold standard for quantifying strength. Laciuga and colleagues study similarly investigated the relationship between clinician perception of coughing sounds and aerodynamic coughing parameters; however, their study focussed only on voluntary coughing (Laciuga et al., 2016). Therefore, a fundamental difference between the two studies is the type of cough being investigated. Despite this, a commonality between the present study and research led by Laciuga (2016) is that both compare clinician perception of coughing quality with varying aerodynamic features. It is also important to note that whilst Laciuga and colleagues (2016) investigated the relationship between voluntary cough aerodynamic features and clinicians' perceptual ratings, the studies focus was on identifying commonalities in clinicians perceptual coughing

ratings rather than a demonstrable statistical correlation. In the absence of research related specifically to reflexive coughing, this study warrants discussion. Laciuga and colleagues (2016) found that voluntary coughs that were perceived as strong and effective shared distinctive aerodynamic features, including high values of PEFR, CVA and TEV. The present study observed some alignment between clinician VAS ratings and extreme values of peak pressure. This suggests that clinicians may be more likely to perceive reflexive coughs with higher peak pressure as stronger coughs. However, given the correlation between mean VAS and peak pressure was only moderate, this potential relationship has limited clinical utility. A further key difference in methodology between the two studies is that Laciuga and colleagues (2016) only allowed for binary ratings of coughing characteristics, such as weak vs strong and effective vs ineffective, which would have restricted the options for ratings and may have resulted in greater agreement among participants. In addition, only 10 coughs were rated which may not have been a representative enough sample to draw solid conclusions about the relationship between clinician's perceptual ratings and coughing aerodynamic features.

The strongest correlation observed in the present study was between VAS mean and reflexive coughing peak pressure. There is limited literature focussing on the predictive relationship between coughing peak pressure and risk of aspiration, for both reflexive and voluntary coughing. A more common measure of coughing efficacy discussed in the voluntary coughing literature is the clinical utility of PCF as a predictor of aspiration risk. The present study identified that PCF had no association with clinician rating of reflexive coughing strength. Whilst voluntary PCF may demonstrate potential clinical utility in the objective assessment of voluntary coughing strength, these findings cannot be applied to reflexive coughing due to poor correlation between reflexive and voluntary coughing physiological measures (Mills et al., 2017). This highlights the need for further research into the relationship between reflexive coughing aerodynamic parameters and coughing efficacy.

### 5.2.2 Acoustic coughing features

The present study found no association between clinician rating of reflexive coughing strength and peak acoustic values. Interestingly, some alignment between clinician VAS

ratings were observed with higher peak acoustic values. This suggests that clinicians may be more likely to perceive reflexive coughs with higher peak acoustic as stronger coughs. However, this observation has no meaningful clinical utility as there was no association observed between peak acoustic and perceptual reflexive coughing strength ratings. Findings are similar to outcomes from Smith and colleagues' (2006) study. Authors explored the relationship between acoustic analysis and spontaneous coughing sounds, utilising perceptual ratings from health professionals (Smith et al., 2006). It was found that clinicians perceptions of coughing qualities did not consistently correlate with objective acoustic measures. Clinicians were more consistent in their identification of the presence of mucus in coughs than they were in their identification of coughs with wheeze. Clinicians were not reliable in their ability to identify a clinical diagnosis from perception of a coughing sound alone.

Smith and colleagues (2006) further discuss that spontaneous coughing acoustic parameters vary considerably among individuals over the course of a day and in different environments. This highlights another limitation of subjective judgements of coughing strength in the clinical setting, which is derived from observations of a single cough or multiples coughs at best. A more appropriate approach may be to monitor coughing quality over a longer period of time. However, this may be challenging to realistically achieve in the clinical setting with time constraints. This suggests that even if clinical utility were to be identified in the acoustic analysis of reflexive coughing, making a clinical judgement from a small sample of coughs may not be a true representation of an individual's abilities. Findings from the present study of no association between clinician rating of reflexive coughing strength and peak acoustic values further highlight issues regarding the validity of clinical acoustic coughing assessment.

### 5.2.3 Improving accuracy in subjective coughing assessment

A further finding from the present study was that experience level in CRT did not influence the strength of the correlation between VAS ratings and physiological features. Both experienced and inexperienced cohorts demonstrated similar strengths of correlation. This suggests that reflexive coughing strength ratings from clinicians with experience in CRT were no more valid in comparison to physiological coughing parameters, than those of clinicians

with no experience. No previous research was identified which investigated the impact that specialised training in coughing strength interpretation had on the validity of perceptions of reflexive coughing sounds.

Miles and Huckabee's study explored the impact that training in CRT had on inter-rater and intra-rater reliability of clinician judgement of coughing strength (Miles & Huckabee, 2013). A cohort of 11 clinician's experienced in CRT underwent an 8-hour CRT training session. An additional cohort of 34 clinicians with no experience in CRT, received no further training in CRT. Both experienced and inexperienced clinicians demonstrated fair-to-moderate agreement. Whilst the sample size of experienced clinicians was small, this study did not demonstrate that training in CRT had a meaningful impact upon reliability of interpretation of reflexive coughing strength. A further study by Miles and colleagues investigated the impact that a 2-hour training session had on clinician inter-rater reliability of interpretation of reflexive coughing strength and presence (Miles et al., 2014). Clinicians were provided with an introduction to the use of CRT and coughing physiology, and also viewed examples of weak, strong and absent reflexive coughs. Clinicians were found to have moderate reliability in their judgments of coughing strength and had substantial agreement regarding coughing presence. Given baseline data regarding clinician reliability levels from the same cohort was not obtained, it is hard to determine the impact that education in CRT and coughing physiology had on clinician reliability in this study.

Whilst these studies included training sessions related to CRT, and exposure to examples of weak and strong reflexive coughing, this training was not a dedicated education program focussing on improvement in perception of reflexive coughing strength. Despite this, the research led by Miles does suggest that broader CRT related training did not translate into reliability levels which would be considered sufficient in the clinical assessment of coughing strength (Miles & Huckabee, 2013; Miles et al., 2014). To determine the potential for improvement in the validity of clinician perception of coughing strength, future research is indicated. Specifically, research investigating the effect of specialised coughing strength training on a clinician's reliability and accuracy in interpretation of coughing strength in comparison to physiological coughing measures. Outcomes from the present study demonstrate only moderate inter- and intra-rater reliability among clinicians' judgements of reflexive coughing strength. Furthermore, clinicians' judgements of reflexive coughing

strength are not validated by physiological coughing measures. Given these findings, further education and professional upskilling is indicated to justify the continued use of subjective judgments of coughing strength to guide dysphagia management.

### 5.3 Influence of sex on perception of coughing strength

The sex of the subjects in the reflexive coughing stimulus videos did not have a statistically significant impact upon the participants VAS strength ratings. The present study did however find a difference in physiological parameters based on sex. Videos involving female subjects had lower peak flow, pressure and acoustic measures when compared to males. Only a third of the subjects in the cough sample video were male. Despite the finding that sex did influence the strength of the physiological parameters, these differences did not translate into differences in participants VAS strength ratings. Feinstein and colleagues similar finding of lower voluntary PCF, peak pressure and peak expiratory flow in females compared to males' highlights the influence of sex on coughing aerodynamics (Feinstein et al., 2017). It should be noted that research led by Feinstein (2017) provided normative data for only voluntary coughing measures. Similar normative data has not been established for reflexive coughing physiological parameters. Given that a poor correlation between reflexive coughing and voluntary coughing measures has been identified (Mills et al., 2017), future research investigating reflexive coughing strength normative data would be valuable.

### 5.4 Limitations

This is first study to investigate the validity of clinicians' ratings of reflexive coughing strength in comparison to coughing measures of peak pressure, peak flow and peak acoustic. Despite recruitment of a large volume of participants, use of standardised stimulus videos, inclusion of both aerodynamic and acoustic comparison measures, and incorporation of a VAS to allow for greater sensitivity in strength ratings, some limitations were evident with this study.

Nebuliser noise is an inherent part of CRT, however the presence of the nebuliser noise in the video clips was amplified due to the manner in which the videos were recorded. Although this element of the study could not be controlled for, nebuliser noise was present across all videos, providing a consistent auditory distraction for all participants across all

samples. Additionally, in the CRT stimulus videos, the recording device was not consistently placed the same distance away from each individual undergoing CRT. This has potential to impact upon the sound quality of the cough. Technical methods to standardise coughing volume in the stimulus videos were explored, however there was not a method identified which was deemed effective to improve or standardise coughing sounds in this study. To account for this limitation, prior to viewing stimulus video clips participants were provided with an audio clip to listen to and use as a guide to adjust their computer volume to a comfortable listening level. Participants were instructed to maintain this consistent volume for all videos. This measure was implemented in an attempt to control for differences in listening volumes among participants. It was not possible to control for type of computer and background noise, factors which may have potential to impact on interpretation of the coughing sounds.

A further challenge related to video selection. Thirty-six videos were selected to represent the 6 reflexive coughs with the highest and lowest values from each of the categories of peak flow, pressure and acoustic. Values from the extreme ends of the sample data were selected to allow for the greater distinction and variety between the reflexive coughing videos. It is acknowledged that selection of coughs with more extreme physiological measures have potential to bias the sample, leaning towards a more heterogenous population. This can in turn impact upon the ICC, making it higher (Costa-Santos, Bernardes, Ayres-de-Campos, Costa, & Costa, 2011) .

**5.5 Clinical Implications**

This study recommends that clinicians should be cautious when using subjective judgements of reflexive coughing strength to draw conclusions about airway protection capabilities. Participants in this study represented an experienced cohort with over 60% of participants having greater that 5 years dysphagia management experience and one third of participants having experience with CRT in the clinical setting. Findings demonstrate that clinicians have only moderate reliability in their judgements of reflexive coughing strength. Furthermore, the limited association between clinicians' ratings of reflexive coughing strength and physiological coughing measures, suggest that clinicians' perceptual judgements are not valid. As a result, dysphagia management plans derived from utilising judgements of

reflexive coughing strength in clinical decision making have potential to be either overly conservative, or conversely, place the patient at risk of aspiration. This reinforces the importance of the using objective swallowing assessment measures, rather than relying on the CSE alone.

**5.6 Future Directions**

This study demonstrated that clinician's strength ratings of reflexive coughing are not validated by physiological measures of peak flow, peak pressure and peak acoustic. Only moderate inter- and intra-rater reliability was calculated for agreement in judgements of reflexive coughing strength. Future research in the following areas would be valuable:

1. Comparing VFSS findings with objective coughing measures to determine whether there is a correlation between effective and ineffective airway clearance of aspirated material and reflexive coughing physiological measures. This would help to establish whether objective measures of reflexive coughing strength can be used to identify individuals at greater risk of aspiration due to ineffective reflexive coughing.
2. It would be useful to undertake research establishing objective reflexive coughing normative data for healthy individuals. This data would serve as a valuable comparison for future studies investigating reflexive coughing strength.
3. Investigation of the impact of specific training in perception of reflexive coughing strength in comparison to objective measures would assist in determining the scope for increased clinician reliability in subjective cough assessment. Collection of baseline data for comparison will be important to determine the impact of training.

These future studies would further determine whether objective measurement of reflexive coughing strength has clinical utility in determining coughing efficacy and aspiration risk, and also whether clinicians can become more reliable in subjective coughing assessment with specialised training.

## 6. Conclusion

This study provides valuable insight into the validity and reliability of clinician's subjective judgments of reflexive coughing strength. Outcomes suggest that the current routine use of subjective judgements of reflexive coughing strength in clinical dysphagia assessment does not provide an accurate representation an individual's ability to protect their airway in the event of aspiration. Further research is indicated to determine the ongoing clinical utility and value of subjective assessment of reflexive coughing strength. Poor clinician reliability and validity of reflexive coughing judgements support the use of objective swallowing and coughing strength assessment to guide clinical dysphagia management and to accurately determine aspiration risk.

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# Appendices

## Appendix 1

***Introduction email***

To *(name of speech-language therapist/department/student),*

The Rose Centre for Stroke Recovery and Research is conducting a study investigating the validity of speech-language therapists' perceptions of reflexive cough strength and inter- and intra-rater reliability of judgements.

I would value your involvement in this study. I have attached a participant information sheet which provides further detail about the study.

The study involves completion of two questionnaires, which will each take no longer than 30 minutes to complete. All responses are anonymous. The questionnaire is administered online and participants are required to complete the two questionnaires a minimum of three days apart. The questionnaires links are below:

**Questionnaire One:**
https://login.qualtrics.com/jfe/preview/SV_8oxSQxzz4reFNFX?Q_SurveyVersionID=current&Q_CHL=preview

**Questionnaire Two:**
https://login.qualtrics.com/jfe/preview/SV_cFIs5aYRDQDiwLP?Q_SurveyVersionID=current&Q_CHL=preview

If you have any questions or require any further information, please don't hesitate to contact me.

Kind Regards,
Jennifer Chittleborough
Maggie-Lee Huckabee PhD

**Appendix 2**

***Social Media message***

We would appreciate involvement from speech-language therapists and speech-language therapy students in a perceptual reflexive cough strength inter- and intra-rater reliability study. You will be required to complete two questionnaires on two different days – each questionnaire will take no longer than 30 minutes to complete. All your responses will be anonymous. Further information can be found by clicking on the questionnaire link below. If you have any questions, please contact jennifer.chittleborough@pg.canterbury.ac.nz

**Questionnaire One:**
https://login.qualtrics.com/jfe/preview/SV_8oxSQxzz4reFNFX?Q_SurveyVersionID=current&Q_CHL=preview

**Questionnaire Two:**
https://login.qualtrics.com/jfe/preview/SV_cFIs5aYRDQDiwLP?Q_SurveyVersionID=current&Q_CHL=preview

**Appendix 3**

***Information Sheet for Participants***

The University of Canterbury
Rose Centre for Stroke Recovery and Research at St George's Medical Centre
Leinster Chambers, Level One
Private Bag 4737
249 Papanui Road
Christchurch, 8140
New Zealand

Telephone: +64 3 369 4827
Email: jennifer.chittleborough@pg.canterbury.ac.nz

02/07/2018

**Validation of speech-language therapists' perceptions of reflexive cough strength against objective measures of flow, pressure and acoustics.**

**Information Sheet for Participants**

I am a speech-language therapist conducting this research project as a part of my Master's Thesis at the University of Canterbury. The purpose of my research is to validate speech-language therapists' perceptions of reflexive cough strength against objective measures of peak flow, peak pressure and peak acoustics. This research will also investigate inter- and intra-rater reliability of speech-language therapists' perceptions of reflexive cough strength.

If you choose to take part in this study, your participation will involve viewing 36 short videos on two separate occasions. The videos will be of individuals undergoing cough reflex testing. You will then be required to rate each reflexive cough on a scale of weak to strong. Videos will need to be viewed on two separate occasions, with a minimum of three days between each viewing. The videos can be viewed on-line and each viewing will take approximately 30 minutes. Your judgements of cough strength will then be validated against previously collected data on peak acoustics, peak airflow and peak pressure. Secondarily, we will evaluate reliability of assessment within and across raters.

This is an anonymous study, meaning no identifying information about participants will be collected. Any responses you provide will be anonymous and your participation is voluntary. Your completion of the questionnaire will serve as your consent to be included in this research study. Please note that once you have completed the questionnaire you will be unable to withdraw your responses at a later date.

The results of the project may be published, but you can be assured of the complete confidentiality of data gathered in this investigation. A thesis is a public document and will be available through the UC Library.

If you would like a summary of the results of this study, please contact me via email (jennifer.chittleborough@pg.canterbury.ac.nz) and a copy will be forwarded to you. Please note, as this is an anonymous study a summary of your individual responses cannot be provided.

I will be carrying out this project as a requirement for my Master's Thesis under the supervision of Professor Maggie-Lee Huckabee, who can be contacted at maggie-lee.huckabee@canterbury.ac.nz . She will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

**Appendix 4**

***Questionnaire One: inter-rater reliability***

**PAGE ONE:**

Validation of speech-language therapists' perceptions of reflexive cough strength against objective measures of flow, pressure and acoustics.

**Survey One:** Inter-rater reliability study

Thank you for taking part in this survey.

**PAGE TWO:**

**Participant Information**
I am a speech-language therapist conducting this research project as a part of my Master's Thesis at the University of Canterbury. The purpose of my research is to validate speech-language therapists' perceptions of reflexive cough strength against objective measures of peak flow, peak pressure and peak acoustics. This research will also investigate inter- and intra-rater reliability of speech-language therapists' perceptions of reflexive cough strength.

If you choose to take part in this study, your participation will involve viewing 36 short videos on two separate occasions. The videos will be of individuals undergoing cough reflex testing. You will then be required to rate each reflexive cough on a scale of weak to strong. Videos will need to be viewed on two separate occasions, with a minimum of three days between each viewing. The videos can be viewed on-line and each viewing will take approximately 30 minutes. Your judgements of cough strength will then be validated against previously collected data on peak acoustics, peak airflow and peak pressure. Secondarily, we will evaluate reliability of assessment within and across raters.

This is an anonymous study, meaning no identifying information about participants will be collected. Any responses you provide will be anonymous and your participation is voluntary. Your completion of the questionnaire will serve as your consent to be included in this research study. Please note that once you have completed the questionnaire you will be unable to withdraw your responses at a later date.

The results of the project may be published, but you can be assured of the complete confidentiality of data gathered in this investigation. A thesis is a public document and will be available through the UC Library.

If you would like a summary of the results of this study, please contact me via email (jennifer.chittleborough@pg.canterbury.ac.nz) and a copy will be forwarded to you. Please note, as this is an anonymous study a summary of your individual responses cannot be provided.

I will be carrying out this project as a requirement for my Master's Thesis under the supervision of Professor Maggie-Lee Huckabee, who can be contacted at maggie-lee.huckabee@canterbury.ac.nz . She will be pleased to discuss any concerns you may have about participation in the project.

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**PAGE THREE:**

Instructions for Survey One

This survey should take approximately 30 minutes to complete. Please allow adequate time as you cannot save the survey half way through. You will need to complete this survey in a quiet room or have headphones available.

1. You will be asked to view 36 videos showing individuals undergoing citric acid cough reflex testing. This test evaluates cough sensitivity to citric acid.

We are interested in your interpretation of cough strength regardless of whether you have prior experience with cough reflex testing.

2. Each reflexive cough will be rated on a scale from weak to strong. This is an example of what the scale looks like:


3. You can watch each video as many times as required.

4. You will be given an example of both a weak and strong cough to help guide your ratings.

**PAGE FOUR:**

Please enter an individualised password. This will need to include at least one letter and one number. For example December22.

You will be required to enter this same password into Survey Two. This password will be used to pair your two surveys for analysis. This password cannot identify you in any manner as this is an anonymous survey. We recommend you write this password down so you can remember it for Survey Two.

**……..**

**PAGE FIVE:**

Demographic Questions

*Are you a student or practicing clinician?*
O Student
O Clinician

*How many years of clinical experience do you have since graduating?*
O 0-2 years
O 2-5 years
O 5-10 years
O 10-15 years
O >15 years
O Student

*Cough reflex testing involves the introduction of a tussive agent (e.g. citric acid) to assess the sensitivity of the vagus nerve sensory fibres necessary for cough.*
*Do you have experience in administering cough reflex testing?*

O Yes
O No

→ if participants select the 'yes' option, they will be directed to the following question

**PAGE SIX:**

*How many years' experience do you have administering cough reflex testing?*

O 1 year
O 2 years
O 3 years
O 4 years
O >5 years

*How many years' experience do you have in dysphagia management since graduating?*
O Student
O 0-2 years
O 2-5 years
O 5-10 years
O 10-15 years
O >15 years

*Please describe your current area of clinical practice.*
O Acute inpatient
O Sub-acute inpatient

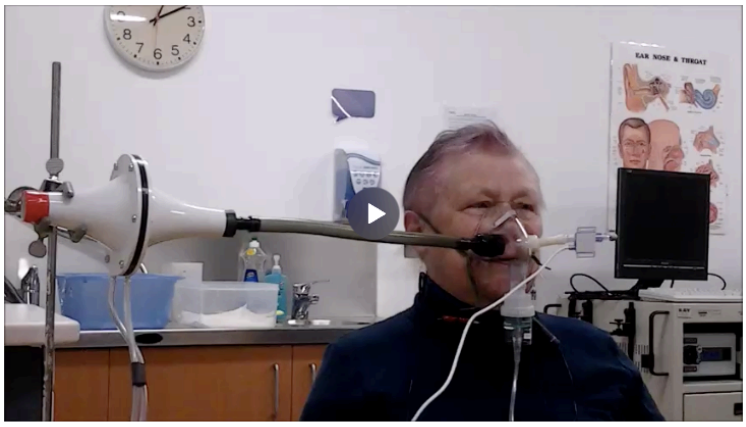
- O Outpatient
- O Private Practice
- O Other ……
- O Student – N/A

**PAGE SEVEN:**

Please play the following video, adjust the volume to a comfortable listening level and maintain this same volume for all the videos you view.


**PAGE EIGHT:**

Please see below an example of a strong reflexive cough. This cough should be used as a reference point to help guide your ratings.



Please rate the strength of this cough on the scale below.

**Weak** **Strong**

Example 1

**PAGE NINE:**

Please see below an example of a weak reflexive cough. This cough should be used as a reference point to help guide your ratings.

Please rate the strength of this cough on the scale below.

**Weak** **Strong**

Example 2

**PAGES 10 - 45: video ratings**

**Video 1**

Please rate the reflexive coughs in the following videos on the scale provided.
The left end of the scale will represent a weaker cough and the right end of the scale will represent a stronger cough.
You can place the marker anywhere along the scale from weak to strong to designate your perception of cough strength for each video.

Please rate the strength of this cough on the scale below.

**Weak** **Strong**

Video 1

**Videos 2 – 36 are similar format to above with inclusion of both the stimulus video and VAS for rating of strength. These images have not been included for the purposes of brevity.

**PAGE 46:**

This study involves two surveys. You have just completed Survey One. We would greatly appreciate if you would also complete Survey Two.

Survey Two involves an intra-rater reliability component. There needs to be a minimum of three days between completing Survey One and Two. As this is an anonymous survey, we cannot send you a personalised reminder email. We suggest adding a reminder to your calendar to complete Survey Two in three days time. Please see the link to Survey Two below. Please copy this link to your calendar or a clipboard so you can easily find it when you return for the second survey. Your input is greatly appreciated.

https://login.qualtrics.com/jfe/preview/SV_cFIs5aYRDQDiwLP?Q_SurveyVersionID=current&Q_CHL=preview

**PAGE 47:**

Thank you for taking part in this survey. We value your input. If you have any questions or you would like to request a summary of the survey results, please contact jennifer.chittleborough@pg.canterbury.ac.nz

**Appendix 5**

***Table of VAS mean, range and standard deviation for each individual reflexive cough with corresponding physiological measures***

| Cough | VAS mean | VAS SD | VAS median | VAS max | VAS min | Peak pressure (mmHg) | Peak flow (L/s) | Peak acoustic (V) |
|---|---|---|---|---|---|---|---|---|
| **1** | 26.93 | 21.08 | 23.5 | 90 | 0 | 4.39 | 2.00 | 0.81 |
| **2** | 84.48 | 18.24 | 89.5 | 100 | 14 | 1.69 | 0.49 | 0.75 |
| **3** | 89.83 | 14.37 | 96.0 | 100 | 42 | 4.71 | 0.66 | 0.51 |
| **4** | 54.91 | 21.58 | 51.0 | 100 | 2 | 3.78 | 1.94 | 0.60 |
| **5** | 69.10 | 25.24 | 72.0 | 100 | 1 | 6.40 | 1.19 | 0.53 |
| **6** | 42.07 | 25.44 | 37.5 | 100 | 5 | 3.77 | 1.87 | 0.02 |
| **7** | 17.16 | 18.41 | 12.0 | 85 | 0 | 1.25 | 1.28 | 0.03 |
| **8** | 11.44 | 14.26 | 5.0 | 56 | 0 | 3.14 | 2.11 | 0.42 |
| **9** | 68.06 | 24.63 | 69.5 | 100 | 3 | 0.66 | 0.32 | 0.02 |
| **10** | 38.20 | 23.09 | 36.5 | 94 | 0 | 0.42 | 0.40 | 0.19 |
| **11** | 7.62 | 10.10 | 4.5 | 48 | 0 | 1.96 | 1.31 | 0.76 |
| **12** | 13.99 | 16.21 | 8.0 | 87 | 0 | 0.35 | 0.18 | 0.16 |
| **13** | 10.32 | 13.45 | 5.0 | 70 | 0 | 0.47 | 0.36 | 0.04 |
| **14** | 74.51 | 17.91 | 78.0 | 100 | 16 | 1.86 | 0.20 | 0.56 |
| **15** | 77.68 | 17.51 | 79.0 | 100 | 23 | 3.80 | 2.15 | 0.08 |
| **16** | 70.84 | 18.89 | 70.0 | 100 | 16 | 1.59 | 0.62 | 0.02 |
| **17** | 32.73 | 23.37 | 28.0 | 84 | 0 | 0.56 | 0.15 | 0.02 |
| **18** | 83.80 | 16.12 | 90.5 | 100 | 43 | 3.59 | 1.86 | 0.11 |
| **19** | 24.88 | 20.47 | 22.5 | 88 | 0 | 0.65 | 0.27 | 0.74 |
| **20** | 7.40 | 9.19 | 3.0 | 33 | 0 | 1.57 | 1.86 | 0.04 |
| **21** | 77.32 | 20.79 | 81.5 | 100 | 12 | 4.96 | 0.82 | 0.74 |
| **22** | 80.50 | 16.77 | 84.0 | 100 | 23 | 3.91 | 1.09 | 0.63 |
| **23** | 41.10 | 21.15 | 40.0 | 91 | 0 | 1.13 | 0.15 | 0.27 |
| **24** | 77.99 | 19.90 | 84.0 | 100 | 17 | 7.69 | 1.54 | 0.68 |
| **25** | 84.68 | 17.15 | 90.0 | 100 | 16 | 4.13 | 1.72 | 0.28 |
| **26** | 53.82 | 23.95 | 54.0 | 100 | 4 | 2.79 | 0.76 | 0.74 |
| **27** | 61.43 | 22.24 | 59.0 | 100 | 15 | 0.98 | 0.40 | 0.04 |
| **28** | 13.43 | 15.72 | 8.0 | 69 | 0 | 0.38 | 0.20 | 0.28 |
| **29** | 61.56 | 22.34 | 62.0 | 100 | 5 | 2.21 | 2.07 | 0.54 |
| **30** | 83.48 | 15.68 | 87.0 | 100 | 34 | 6.57 | 2.17 | 0.33 |
| **31** | 73.67 | 19.25 | 75.5 | 100 | 10 | 2.41 | 0.25 | 0.75 |
| **32** | 55.67 | 22.30 | 57.5 | 100 | 10 | 5.96 | 0.78 | 0.64 |
| **33** | 18.11 | 21.27 | 7.0 | 72 | 0 | 0.22 | 0.57 | 0.17 |
| **34** | 32.72 | 21.82 | 32.5 | 89 | 0 | 0.65 | 0.19 | 0.26 |
| **35** | 5.38 | 12.42 | 0.0 | 70 | 0 | 0.36 | 0.13 | 0.01 |
| **36** | 65.11 | 24.65 | 69.5 | 100 | 0 | 3.26 | 0.63 | 0.74 |